BBC

WHAT CAN COSMIC RAYS TELL US ABOUT THE PYRAMIDS?

FOCUS

SCIENCE AND TECHNOLOGY

UNLOCKING THE SECRETS OF THE BRAIN

How 'minibrains' being grown in labs could reveal what makes us human

* SCIENCE HACKS FOR A PERFECT CHRISTMAS *

PLUS

CAN MATHS DEFEAT TERRORISM?

MEET THE MODERN-DAY MAMMOTH HUNTERS

Garry Kasparov on AI
Is it really a threat to our existence?

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Men's voices get **higher pitched** as they age → p90

WELCOME

Allow me to borrow one of many great quotes from Douglas Adams: "If you try and take a cat apart to see how it works, the first thing you have on your hands is a nonworking cat".

Adams was talking about the ineffable nature of life itself, but I think his words apply pretty well to the study of our brains. While dissections, scans and experiments have taught us a huge deal about the brain and its underlying structures and functions, we're still left with some gaping holes in our knowledge. For instance, we know most of the population uses the left hemisphere of their brain to handle language, but we don't know why that's the case. We understand, to a degree, what changes in brain function lead to autism spectrum disorder, but we don't fully understand what causes these changes in the first place.

This is where 'minibrains' come in. They start life as a bunch of skin cells which are bathed in some genes that effectively hit a cellular rewind button, turning them back into stem cells, the putty from which life is made. These are then nurtured into brain cells which, with a little encouragement, coalesce into grey matter. As they develop, their growth is recorded (and in some cases their genes altered) to reveal piece-by-piece how our brain works. Think of it like taking apart a mechanical watch and putting it back together – forget to put out a cog back in, and you'll find out why it was useful in the first place. This is opening up a whole new way to understand the brain and how it works – find out what's being uncovered on p38.

Have a great Christmas (and find out how to really nail it on p48).

Daniel Bennett

Daniel Bennett, Editor

WHAT WE'VE FOUND OUT THIS MONTH

Cosmic rays can be used to see inside **pyramids and volcanoes** → p14

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COVER: MAGIC TORCH

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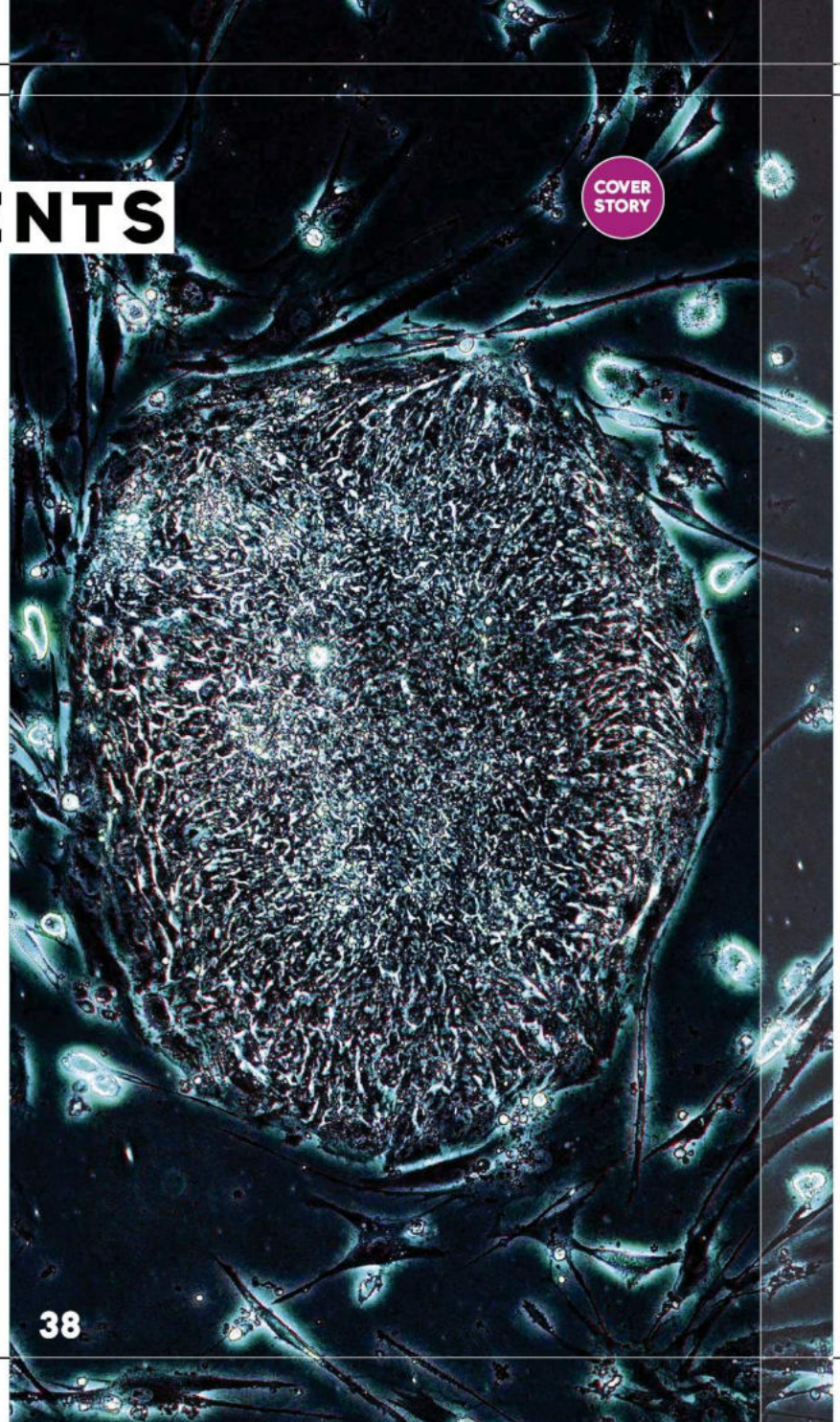

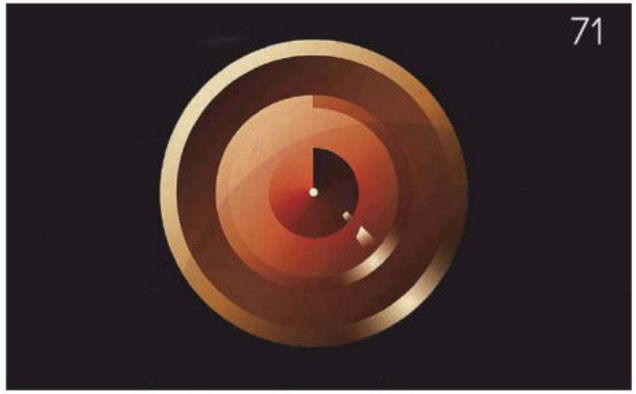

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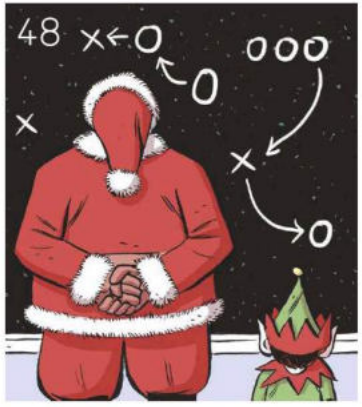

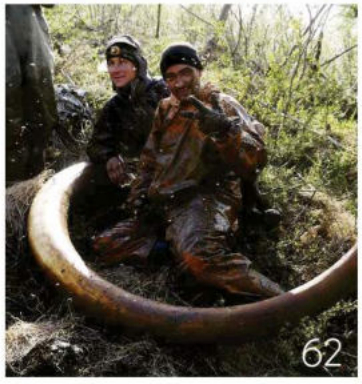

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The latest special edition from the *BBC Focus* team is your ultimate guide to the prehistoric beasts that roamed the planet millions of years ago.
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She's having a bubble!

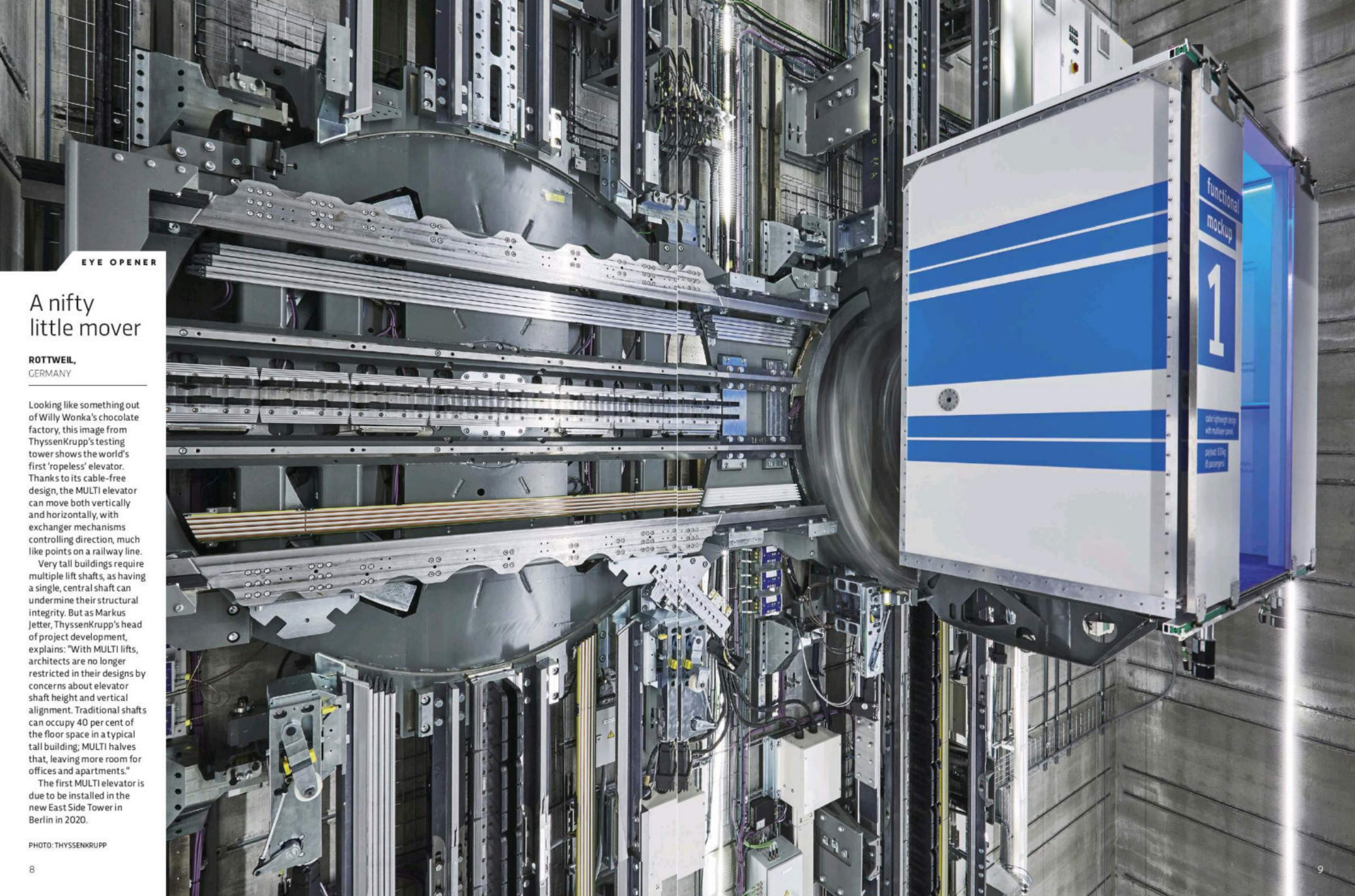
KEDAH,
MALAYSIA

This is a social wasp belonging to the genus *Ropalidia*, which is commonly found across southeast Asia. Most insects belonging to this genus produce nests by swarming, in a manner similar to honeybees – an unusual behaviour for wasps. However, in this particular species, a single mated female starts a nest in much the same way that wasps in the UK do.

"In this photo, the female has constructed a paper nest from wood fibres and water – natural papier maché – and in the cells you can see developing larvae. These will turn into adult females that look exactly like their mother queen, but instead of laying eggs, they will become workers, expanding and defending the nest and tending to the eggs and larvae," said entomologist and BBC presenter Adam Hart. "She has removed water from the open nest using her mouth. Wasps, like their relatives the bees and ants, are scrupulous in keeping conditions in their nests just right for rearing the young."

Unlike worker wasps in the UK, which remain more or less sterile throughout their lives, *Ropalidia* workers have the capacity to become breeding females that can replace the mother queen if she is lost.

PHOTO: CATERS NEWS



EYE OPENER

A nifty little mover

ROTTWEIL,
GERMANY

Looking like something out of Willy Wonka's chocolate factory, this image from ThyssenKrupp's testing tower shows the world's first 'ropeless' elevator. Thanks to its cable-free design, the MULTI elevator can move both vertically and horizontally, with exchanger mechanisms controlling direction, much like points on a railway line.

Very tall buildings require multiple lift shafts, as having a single, central shaft can undermine their structural integrity. But as Markus Jetter, ThyssenKrupp's head of project development, explains: "With MULTI lifts, architects are no longer restricted in their designs by concerns about elevator shaft height and vertical alignment. Traditional shafts can occupy 40 per cent of the floor space in a typical tall building; MULTI halves that, leaving more room for offices and apartments."

The first MULTI elevator is due to be installed in the new East Side Tower in Berlin in 2020.

PHOTO: THYSSENKRUPP

REPLY

Your opinions on science, technology and *BBC Focus*

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MESSAGE OF THE MONTH

SLEEP STRUGGLES

This morning my mother sent me your survey on sleep paralysis and a condition that I was not aware of, exploding head syndrome, which sounds terrible. I completed the survey and added myself to the optional list at the end with the hope of maybe hearing some of your findings. I have suffered from sleep paralysis since I was a child, and at least three or four times a week. I get it the worst when over-tired and just lying down for bed.

My father is a doctor who specialises in the diagnosis of epilepsy and other neurological conditions. My question to you, I suppose, is in regards to my father's explanation of how sleep paralysis works and whether he is right. Dad told me that when you fall asleep your body goes into a state of sleep called REM (rapid eye movement) where by your eyes are darting around behind your eyelids as you dream.

The problem with this is that if this happened every time we went to sleep we would be kicking, punching, walking around, you name it when we are completely asleep. So to combat this the body essentially disconnects its brain from its central nervous system as a preventative measure. According to Dad, sleep paralysis is when your brain is awake but remains cut-off from your central nervous system. He also went on to explain that this also accounts for people's description of seeing demons or aliens, as they are not completely awake and remain partially asleep.

I have never had such an experience as that. I can only open my eyes and control my breathing, I can however pull myself out of it, and my girlfriend will shake me awake which works.

Matthew Haindl, Sydney, Australia

I'm glad to hear you found our survey (anyone that hasn't can do so at sciencefocus.com/bigsleepsurvey). Your dad is essentially right: sleep paralysis happens when a person wakes up before REM sleep is finished. Your body's ability to move hasn't been switched on yet – even though you're conscious. In some cases, this combination can fuel hallucinations of witches, ghosts and ogres. The NHS (www.nhs.uk/conditions/sleep-paralysis) is a good resource if you want to find out more. Plus, keep an eye on sciencefocus.com for our follow-up piece... ***Dan Bennett, Editor***

FAREWELL

I was saddened to read that this month's edition carried Robert Matthews' last column for the magazine (November, p31). I've been a subscriber for many years, and this was the column I'd often turn to first. Please forward my thanks for many years of enjoyable and thought-provoking comment.

Steve, via email

HEAR ME NOW

I feel the need to hold Russell Deeks to account on a few points in his reply to Roger Britton's Message Of The Week (November, p14). Cards on the table – I am a music lover and audiophile who prefers CD, though agnostically. I prefer the convenience and the fact that discs do not wear rather than possessing an 'ideological' view.

Russell perpetuates a myth or two, and is rather vague in his arguments. Most people know that CD's original sampling rate was set because theory suggested that higher frequencies were inaudible and therefore irrelevant. The opinion that this was a mistake and that inaudibly high frequencies *did* affect what we hear gained ground steadily, and SACD and DVD-Audio were created to address this weakness. The latter went nowhere, and large scale double-blind testing has shown that even discerning listeners cannot tell the difference between CD and SACD (I own SACDs and I certainly can't) with the caveat that at high volumes, a lower noise floor exists in SACD. I am therefore deeply sceptical about the claim that "much of the harmonic information is lost" in CD. I would suggest that in using imprecise terminology and hinting at lost 'harmony', this is an appeal to the heart, not the head.

And if sampling rate beyond CD-grade is not audible, the fact that much of today's vinyl was originally recorded in digital form is perhaps best not contemplated too much...

I also cannot tell the difference between CD copies taken from vinyl and the original source, suggesting either that there is no magic that doesn't translate into ones and zeros, or that I am cloth-eared beyond redemption. I have no reason to believe the latter!

Simon Bartlett, via email

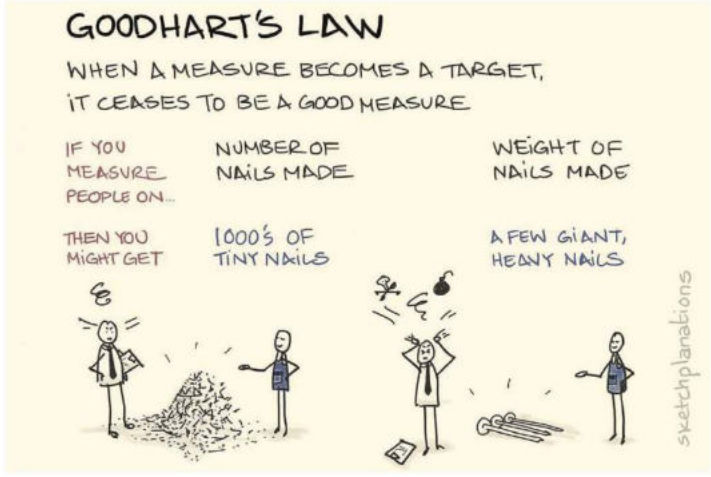
Nearly all music today is indeed recorded digitally, but Simon conveniently overlooks the fact that nearly all modern studios have also moved to 24-bit/96kHz recording as a minimum – partly because this enables more of those 'inaudible' frequencies to be heard! As for the 16-bit/44.1kHz sampling rate for CD, as I understand it this rate was chosen not because "higher frequencies were inaudible and therefore irrelevant," but because such a rate would allow a 60-minute album to fit onto one 10.5cm disc – the initial size proposed for CDs. This was later increased to 12cm to allow a playback time of 74 minutes – long enough for Beethoven's 9th Symphony to fit onto one disc.

PHOTOS: GETTY, @SKETCHPLANATOR

Simon Bartlett says CD is as good as sound can get

However, as I said last month, what any of us can or can't hear is entirely subjective – we certainly aren't suggesting Mr Bartlett should replace his CDs if he doesn't want to! ***- Russell Deeks, contributing editor***

▼ Following Robert Matthew's column on Goodhart's Law (October, p23), we enjoyed this illustration by @sketchplanator on Twitter, which explains the idea perfectly!



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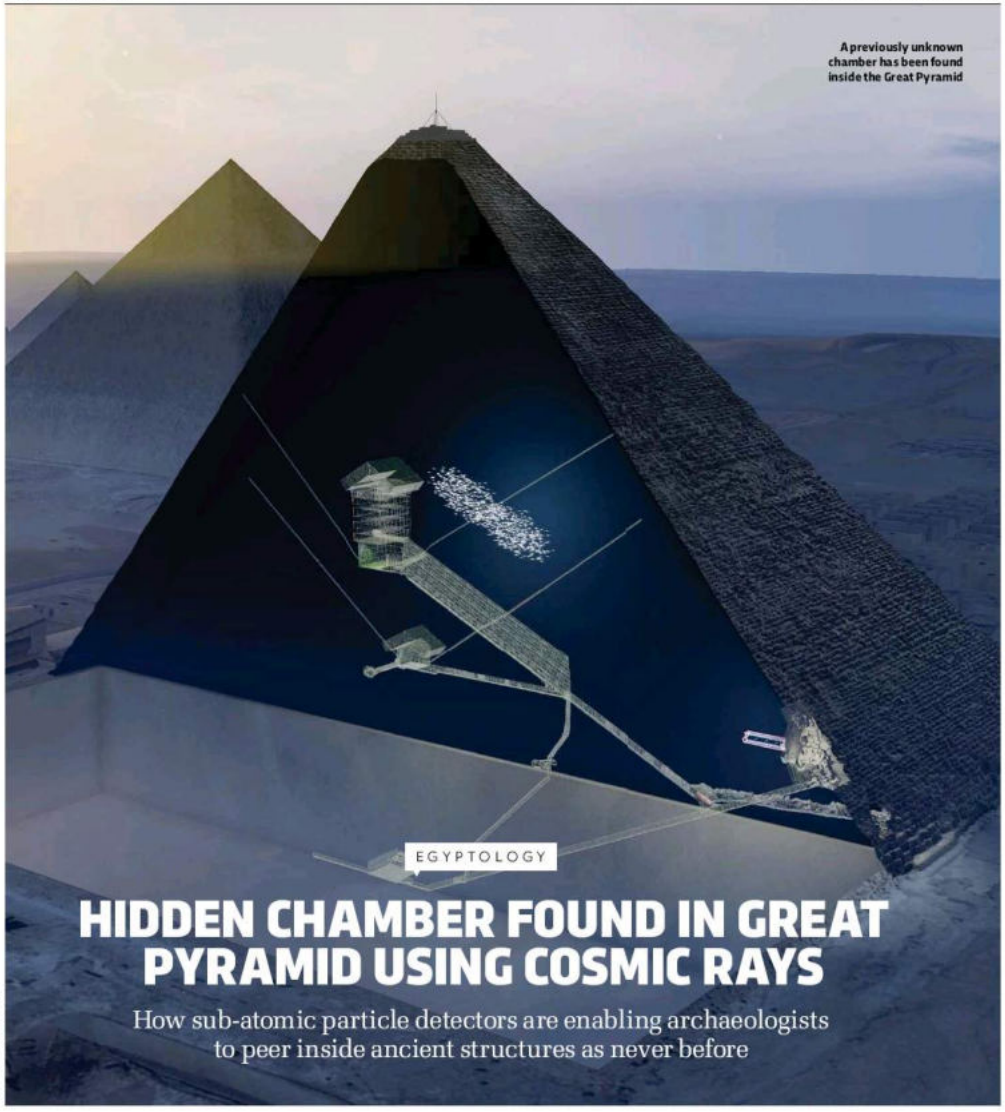
CHRISTMAS 2017 | EDITED BY JASON GOODYER



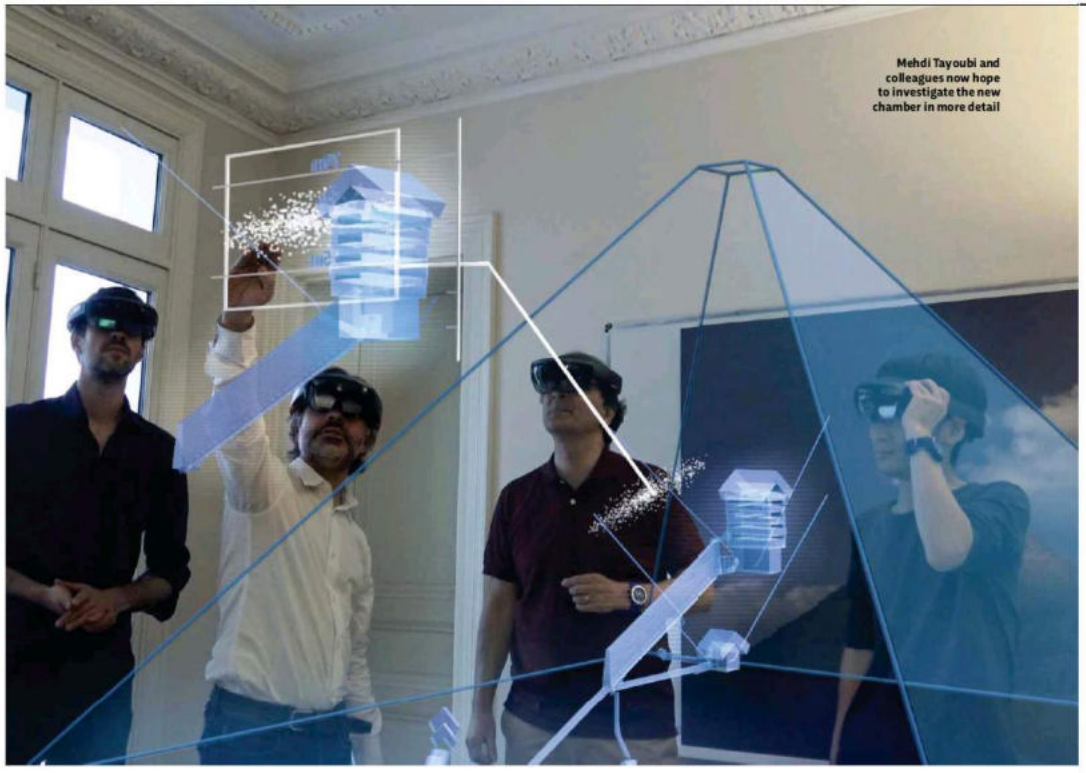
A previously unknown chamber has been found inside the Great Pyramid

EGYPTOLOGY

HIDDEN CHAMBER FOUND IN GREAT PYRAMID USING COSMIC RAYS

How sub-atomic particle detectors are enabling archaeologists to peer inside ancient structures as never before

PHOTO: SCANPYRAMIDS



Mehdi Tayoubi and colleagues now hope to investigate the new chamber in more detail

Archaeologists have uncovered a mysterious chamber deep within the Great Pyramid of Giza, using a cutting-edge imaging technique based on the detection of subatomic particles created by cosmic rays.

Dubbed the ScanPyramids Big Void, after the name of the project that discovered it, the cavity is approximately 30m long and 3m high and is situated above the Grand Gallery, a large corridor that connects the two largest of the iconic structure's three main chambers.

The Great Pyramid, also known as Khufu's Pyramid, was built during the reign of Pharaoh Khufu, who reigned from 2509 to 2483 BC. Despite years of research, there is no consensus on exactly how the monument was constructed.

As yet the precise structure and role of the newly discovered void remain unknown, but the findings may pave the way for further studies that could help researchers to understand the pyramid and its construction process.

"No important internal structures have been found in the Pyramid since 820AD, when the Calife Al Mamun dug a tunnel and penetrated inside, revealing most of the structure we know today," said Prof Mehdi Tayoubi from Cairo University. "Finding something as important, in terms of size, as the Grand Gallery is an important breakthrough."

"OUR DISCOVERY IS THE FIRST DEMONSTRATION OF THE POTENTIAL OF COSMIC RAY IMAGING TO GATHER NEW INFORMATION IN ARCHAEOLOGY"

The void was discovered using sensors tuned to detect muons, particles that are created when high energy cosmic rays slam into molecules in the upper atmosphere. By piecing together data from several different locations, the team were able to form a three-dimensional image of the pyramid's internal structure.

"Our discovery is the first demonstration of the potential of cosmic ray imaging to gather new information in archaeology," said Nagoya University's Kunihiro Morishima. "The Big Void has not been touched by anyone since the building of the pyramid 4,500 years ago, so if there are some artefacts inside the big void, they should be very important for understanding ancient Egypt."

The team now plan to take further scans of the Big Void, in order to determine its shape and structure in more detail.

PHOTOS: SCANPYRAMIDS, SCIENCE PHOTO LIBRARY, HIROYUKI TANAKA X2

WHAT ARE MUONS?

Muons are negatively charged subatomic particles that come from the lepton family – the same family as electrons, though muons are much heavier. Like electrons, they are not thought to be made up of any smaller particles, making them a so-called elementary particle. They were first discovered in 1936 by Nobel Prize-winning physicist Carl Anderson and Seth Neddermeyer at Caltech in the US while they were studying cosmic radiation.

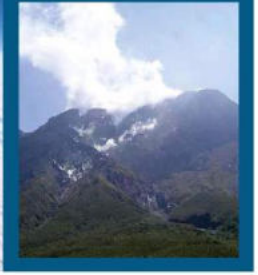
Around 10,000 muons reach every square metre of the Earth's surface each minute. They are created when cosmic rays – high energy radiation that originates from outside the Solar System – collide with molecules in the upper atmosphere. As muons don't interact very strongly with matter, they are able to travel through solid objects – including our own bodies – and penetrate deep into the surface of the Earth.

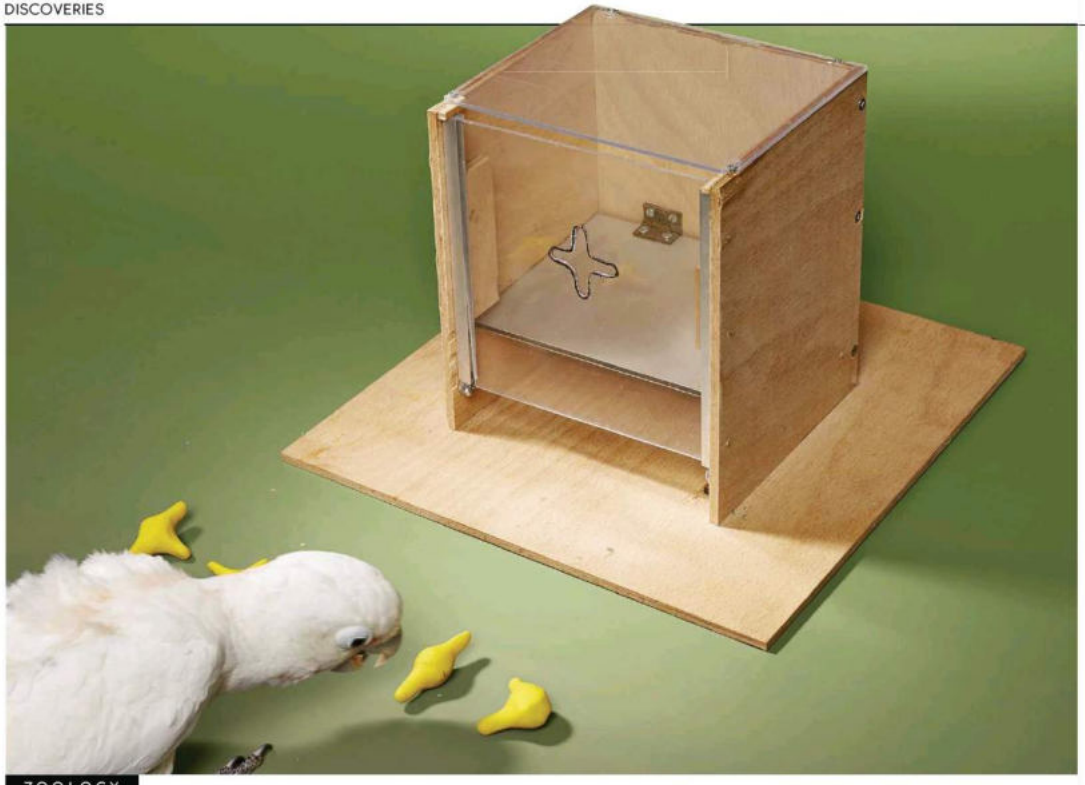
Cosmic rays from outside our Solar System send muons cascading through it

WHAT IS MUON TOMOGRAPHY?

Thanks to their ability to penetrate deep into solid matter, muons can be used to image the internal structure of objects in a manner similar to X-rays. Detectors are placed in strategic positions around the object to be scanned, and left running for several months. Over time a pattern of detections builds up, revealing the void areas where the muons passed through without issue, and the denser areas where some of them were absorbed or scattered. The internal structure of the object can therefore be discerned.

The technique has previously been used to reliably image and create 3D models of the interior of volcanoes, making clear the distinction between rocks of different temperatures, water, and voids beneath the surface, and also to probe the ruins left behind in the wake of the Fukushima Daiichi nuclear disaster.





Goffin's cockatoos have shape-recognition abilities akin to those of a human two-year-old

PHOTOS: BENE CROY, GETTY

ZOOLOGY

COCKATOOS ARE SKILFUL SHAPE-SORTERS

Who's a clever boy, then? Goffin's cockatoos, a species of small parrot native to Australasia, have been shown to have similar shape-recognition abilities to a human two-year-old.

Though not known to use tools in wild, the birds have proved adept at tool use in captivity. In a recent experiment at the University of Vienna and the University of Veterinary Medicine Vienna, cockatoos were presented with box with a nut inside it. The clear front of the box had a 'keyhole' in a geometric shape, and the birds were given five differently shaped 'keys' to choose from. Inserting the correct 'key' would release the nut.

In humans, babies can put a round shape in a round hole from around one year of age, but it will be another year before they're able to do the same with less symmetrical shapes such as squares, triangles or crosses. This ability to recognise that a shape will need to be rotated into a specific orientation before it will fit is called an 'allocentric frame of reference'. In the tests in Vienna, the Goffin's cockatoos were able to select the right tool for the job, in most cases, by visual recognition alone. Where trial-and-error was involved, the cockatoos fared better than apes and monkeys have in similar tests.

"This indicates that [Goffin's cockatoos] do indeed possess an allocentric frame of reference when moving objects in space, similar to two-year-old toddlers," said Alice Auersperg, head of the Goffin lab at the University of Veterinary Medicine Vienna.

The next step, say the researchers, is to try and work out whether the cockatoos rely entirely on visual clues, or also use a sense of touch in making their shape selections.

PALAEONTOLOGY

DINOSAUR-KILLING ASTEROID IMPACT WAS WORSE THAN WE THOUGHT

Some 66 million years ago, an asteroid struck the Yucatan peninsula in Central America, forming the Chicxulub crater and wiping out the dinosaurs in what is known as the Cretaceous–Paleogene (K–Pg) extinction event. But two new pieces of research suggest that this impact was even more cataclysmic than was previously believed.

A new study published in the journal *Geophysical Research Letters* shows that up to three times as much sulphur may have been released into the atmosphere as a result of the impact than previous models have suggested. This would have led to a longer period of global cooling, which helps to explain the devastating effects on the Earth's fauna at the time.

"Many climate models can't currently capture all of the consequences of the Chicxulub impact, due to uncertainty in how much gas was initially released," said the paper's lead author Joanna Morgan, a geophysicist at Imperial College London. "We wanted to revisit this significant event and refine our collision model to better capture its immediate effects on the atmosphere."

But perhaps more surprising are the results of a study conducted at Japan's Meteorological Institute and Tohoku University. In a paper just published in the journal *Nature*, researchers Kunio Kaiho and Naga Oshima show that the high levels of soot and sulphurous gas that caused the mass extinction were a result of the rocks on the peninsula being particularly rich in hydrocarbons. Such rocks covered only around 13 per cent of the world's surface, and had the impact occurred in a different area where the rocks were less rich in hydrocarbons, the dinosaurs would most likely have survived.

In other words, the chances of the asteroid impact killing off the dinosaurs as it did were only slightly more than one in 10. Unlucky...

If the Chicxulub meteor had shifted trajectory slightly, dinosaurs could still be roaming the Earth today

IN NUMBERS

SIX MONTHS

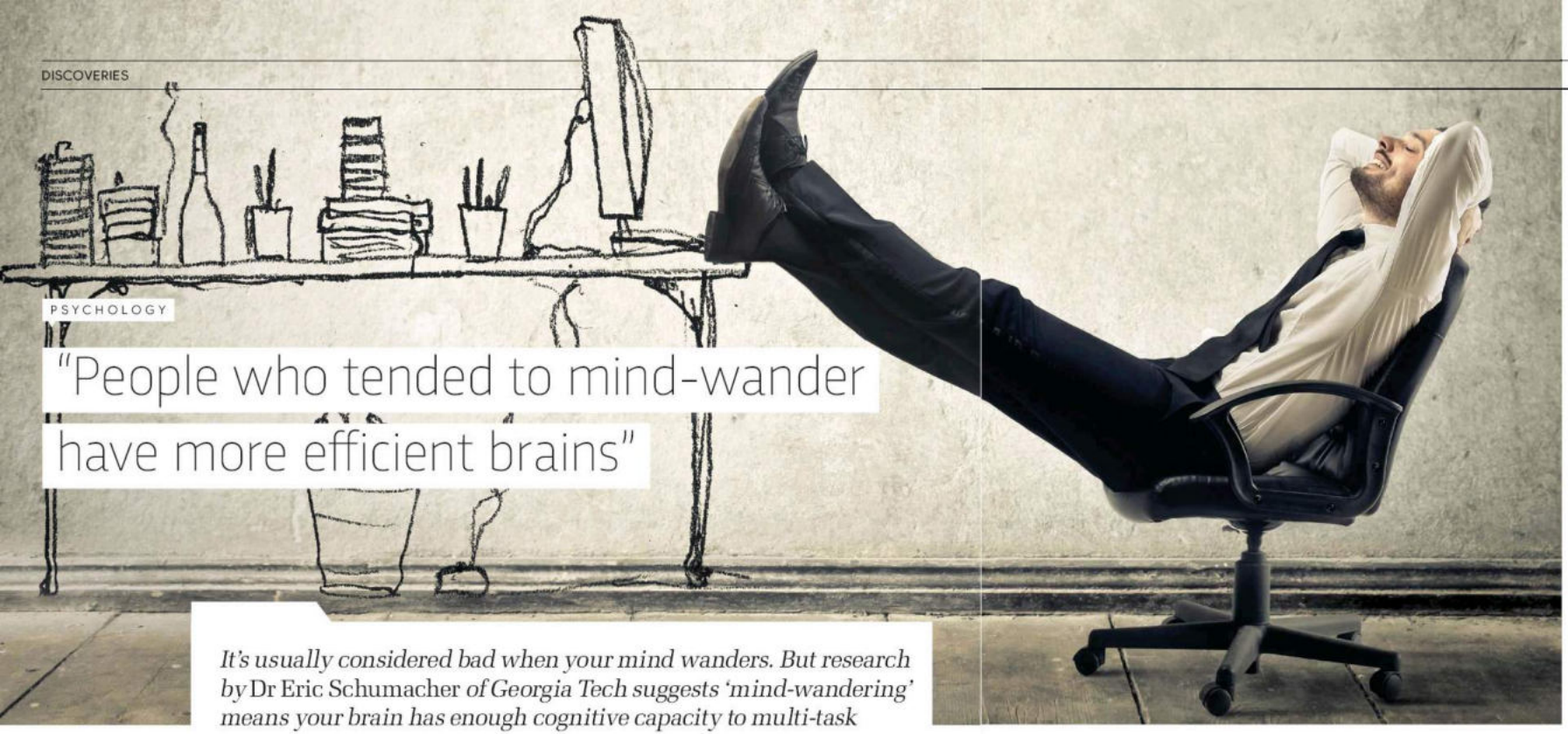
The average time is takes to shed extra pounds put on through over-indulging during the holiday period, as estimated by a team at Tampere University, Finland.

23 TERAWATT HOURS

The amount of energy used globally by Bitcoin miners each year. That's just short of the 24.8 terawatt hours generated by renewable energy worldwide in 2016.

20 MILLION

The number of lives saved worldwide by the measles vaccine since the turn of the millennium, as calculated by the Centers for Disease Control and Prevention.



PSYCHOLOGY

"People who tended to mind-wander have more efficient brains"

It's usually considered bad when your mind wanders. But research by Dr Eric Schumacher *of Georgia Tech suggests 'mind-wandering' means your brain has enough cognitive capacity to multi-task*

What's the difference between daydreaming and mind-wandering?
Researchers are interested in identifying different types of what are called 'off-task behaviours'. Mind-wandering is a coherent train of thought – you might be thinking about the fact that you have to pick up your dry cleaning, pick up the kids from school, feed the dog. Whereas daydreaming is not goal-directed – a creative endeavour, thinking about things that don't exist. We were interested in other abilities that relate to the tendency to mind-wander.

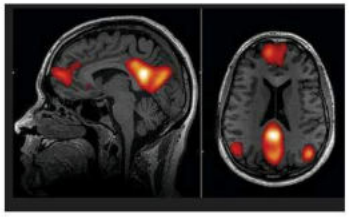
How did you measure mind-wandering?
We gave over 100 participants questions like, 'On the bus, do you think about what you had for breakfast?' All of our minds tend to wander sometimes, but there are individual differences. So we measured brain activity at rest: we put participants in an MRI scanner and had them lie there in the dark, staring at a plus sign on a screen, for about 10 minutes. Their minds were probably wandering at that time.

Which brain circuits are involved?
MRI scans are useful for identifying networks of brain regions that work together to carry out behaviour. One is the 'default mode network', a collection of regions in the middle-front and middle-back part of your brain related to 'internally-focused attention'. When you're thinking about memories or your mind is wandering, those regions are more active. One of the measures we had was how connected that default mode network was.

What did you find out?
There's an idea that when your default mode network is connected and active at rest, your brain is likely to be more efficient at other times. To test this idea, we had subjects perform the 'remote associates' task, a measure of creativity. Participants are given three words and have to identify a word that links them together – for instance, they might see the words 'widow', 'monkey' and 'web', and they have to think of the word 'spider'.

We also had a measure of fluid intelligence, the ability to solve problems, called Raven's advanced progressive matrices task. In this test, you get given eight shapes and have to identify the ninth one that would fill in the pattern.

BELOW: **The brain's 'default mode network' has previously been linked to daydreaming**



PHOTOS: SHUTTERSTOCK, JOHN GRANER ILLUSTRATIONS: DAN BRIGHT

ABOVE: **Letting your mind wander may not be such a bad thing after all**

Our key finding was that people who tended to mind-wander more during their daily lives tended to have more efficient brains – they tended to score higher on the creativity and fluid intelligence tasks. What we show is that there may be times when our minds wander that's not necessarily maladaptive. We can think about other things that are important while also monitoring the task at hand, and switch back without much of a detriment in understanding or performance. It's not an explicit decision, just something our information-processing system is aware of, and allocates [mental] capacity to achieve our many goals.

So if mind-wandering isn't a bad thing, could it actually be good for you?
We would need to know much more. Can we measure an individual's intelligence, their creativity? Then we might be able to say: is their mind-wandering maladaptive or adaptive? For now, a practical implication of this research might be that if a person finds themselves mind-wandering a lot and they're still getting good grades in school, still performing efficiently at work, then maybe they shouldn't worry about the fact that sometimes they find themselves mind-wandering.

THEY DID WHAT?!

SHEEP TRAINED TO RECOGNISE CELEBRITIES

What did they do?
A team at the University of Cambridge placed eight sheep in a pen, one at a time. At one end, they displayed two photographs on computer screens – one of a celebrity and one of a random person – and placed infrared detectors on each of them. The celebrities used were Fiona Bruce, Jake Gyllenhaal, Barack Obama and Emma Watson. When the sheep moved towards the celebrity photograph they received a food reward. If they chose the wrong photograph, a buzzer would sound and they would receive nothing.

What did they find?
After training, the sheep were able to choose the photograph of the celebrity face eight times out of ten from the front, and around seven times out of ten when show the face from the side.

Why did they do that?
"Sheep are long-lived and have brains that are similar in size and complexity to those of some monkeys. That means they can be useful models to help us understand disorders of the brain, such as Huntington's disease, that develop over a long time and affect cognitive abilities," said study leader Prof Jenny Morton.

ZOOLOGY

NEWLY IDENTIFIED ORANGUTAN IS WORLD'S MOST ENDANGERED GREAT APE SPECIES

A population of orangutans that lives in a remote part of northern Sumatra, and that was only discovered in 1997, has now been identified as a separate species. With only around 800 individuals known to exist, it's now also the most threatened of all great ape species.

It was once believed that all orangutans were one species, but since 1996 science has recognised two: the Bornean and Sumatran orangutan (*Pongo pygmaeus* and *Pongo abelli*, respectively). The following year, a long-rumoured population of orangutans living in the Batang Toru region of northern Sumatra was seen for the first time, but initially the apes were thought to be of the species *P. abelli*.

However, close study of an adult skeleton found in 2013 has revealed significant differences in the skull and teeth of the Batang Toru apes, leading to their new classification: *Pongo tapanuliensis*, or the Tapuli orangutan. Genomic analysis suggests that the species must have split from *P. abelli* around 70,000 years ago.

"The Batang Toru orangutans appear to be direct descendants of the initial orangutans that had migrated from mainland Asia, and thus constitute the oldest evolutionary line within the genus *Pongo*," said lead author Alexander Nater, from the University of Zurich.

With just 800 individuals known, *P. tapanuliensis* goes straight to the top of the endangered great apes league table, not least because large areas of its habitat are threatened by plans to build a hydroelectric dam in the region. The discovery isn't great news for *P. abelli* in that regard, either – there are now 800 less of them than was previously believed.

Closer examination of a skeleton found in 2013 has revealed that *P. tapanuliensis* is a separate species

PHOTOS: ANDREW WALMSLEY; NATER ET AL; UNIVERSITY OF WARWICK/MARK GARLICK ILLUSTRATION: DANIEL BRIGHT

SPACE

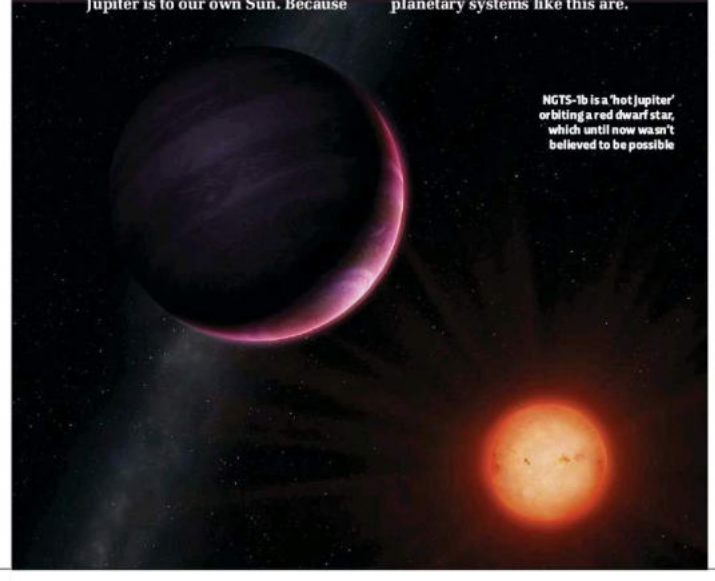
MASSIVE NEW EXOPLANET SHOULDN'T, IN THEORY, EXIST

Well, this is a bit of a headscratcher. Recently discovered exoplanet NGTS-1b is causing astronomers to rethink their ideas about how planets come into being, because according to current theories, such a large planet should not be able to from around a star as small as its parent.

NGTS-1b is the first exoplanet discovered by the Next-Generation Transit Survey. This international initiative, based at the Paranal Observatory in Atacama, Chile, uses an array of 12 telescopes to scan a small area of sky repeatedly over several months. By detecting a dip in brightness, every 2.65 days, of the light coming from a red dwarf star dubbed NGTS-1, astronomers were able to determine that a 'hot Jupiter'-type exoplanet is orbiting the star.

'Hot Jupiters' are gas giants (like our own Jupiter) which are much closer to their parent star than Jupiter is to our own Sun. Because they're so large and orbit their parent so closely, they cause significant, regular dips in its brightness, and as a result are among the easiest exoplanets to spot. It's believed they form, like Jupiter, in the outer reaches of a solar system, before migrating inwards – but such an explanation assumes the presence of a main sequence star such as our own Sun. According to current theories, a red dwarf like NGTS-1, which is only half that size, should only have enough gravity to form rocky planets, not gas giants.

"Having worked for almost a decade to develop the NGTS telescope array, it's thrilling to see it picking out new and unexpected types of planets," said Prof Peter Wheatley of the University of Warwick, who is head of the NGTS project. The team's next challenge will be to work out how common planetary systems like this are.



NGTS-1b is a 'hot Jupiter' orbiting a red dwarf star, which until now wasn't believed to be possible

DOGS

People have more empathy for dogs than their fellow humans, a study at Northeastern University, Boston has found. Subjects who read about dogs being beaten were more moved than those who read similar stories about humans.

THE AMISH

A genetic mutation found in some members of an Amish community in Indiana, USA can help them to live up to a decade longer than people without it, a study at Northwestern University has found.

GOOD MONTH

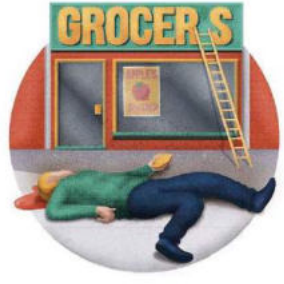
BAD MONTH

FAST EATERS

Taking your time at the dinner table could lead to a trimmer, healthier you. A study led by the American Heart Association has found that slow eaters are significantly less likely to suffer from obesity, heart disease and stroke.

GRAMMAR PEDANTS

Researchers from the University of Pennsylvania have found that the English language is evolving by random chance, and is subject to the same 'drift' found in natural selection in the animal kingdom.



Ayahuasca has been used in religious rituals since at least the 16th Century

MENTAL HEALTH

HALLUCINOGENIC DRUG BREWED BY AMAZONIANS COULD BE USED TO TREAT ALCOHOLISM AND DEPRESSION

A psychedelic drug traditionally used in South American shamanic ceremonies could be used to treat alcoholism and depression, new research from the University of Exeter and University College London suggests.

Previous studies have suggested that LSD and magic mushrooms can help alcoholics tackle their addiction, but now ayahuasca, a psychedelic brew often consumed in rituals in the Amazon region, has also shown promise.

The brew is made from a blend of the bush *Psychotria viridis* and the stems of the *Banisteriopsis caapi* vine. It is used in rituals by indigenous tribes and religious groups in the region, as well as being increasingly popular with visitors seeking psychedelic experiences. The resulting concoction contains dimethyltryptamine (DMT), a Class A prohibited drug in the UK.

IF YOU ARE WORRIED ABOUT YOUR ALCOHOL USE, CONTACT ALCOHOLICS ANONYMOUS ON 0800 917 7650. IF YOU ARE CONCERNED ABOUT YOUR MENTAL HEALTH, VISIT MIND.ORG.UK

Taking Global Drug Survey data from more than 96,000 people worldwide – including 527 ayahuasca users, 18,138 who used LSD or magic mushrooms and 78,236 non-drug users – the team found that ayahuasca users reported lower problematic alcohol use than people who took LSD or magic mushrooms, and higher general well-being than other respondents.

"These findings lend some support to the notion that ayahuasca could be a powerful tool in treating depression and alcohol use disorders," said lead author Dr Will Lawn, of University College London. "Recent research has shown ayahuasca's potential as a psychiatric medicine, and our current study provides further evidence that it may be a promising treatment – though it's important to note that these data are purely observational and do not demonstrate causality."

PHOTOS: ALAMY, NASA/ESA/G BACON/STSCI

SPACE

MYSTERIOUS ZOMBIE STAR KEEPS EXPLODING, BUT WON'T DIE

Morrissey was right – there *is* a light that never goes out! An international team of astronomers has made a bizarre discovery: a star that has exploded repeatedly, yet carries on shining.

When stars of a certain size reach the end of their lifecycle, they explode in energetic cosmic events known as supernovae. Such explosions have been recorded by astronomers thousands of times, and in every recorded case, such an explosion has marked the death of a star. But now scientists seem to have found an exception in iPTF14hls, a supernova that has exploded at least twice in the past 70 years.

"This supernova breaks everything we thought we knew about how they work. It's the biggest puzzle I've encountered in almost a decade of studying stellar explosions," said Dr Iair Arcavi of Las Cumbres Observatory.

iPTF14hls was discovered in 2014 by researchers at Caltech. At first it appeared normal, but seven months after it faded it began growing in brightness. When astronomers went back and looked at archival data, they found evidence of an explosion in 1954 at the same location. The star has somehow survived the first explosion, only to explode again in 2014.

One potential explanation has to do with the star's mass. Having at least 50 times the mass of our Sun, it could have been big enough to be the first example of a theorised event known as a Pulsational Pair Instability Supernova – a star so massive and hot that it created antimatter at its core, which in turn caused it to undergo repeated explosions.

"This is one of those head-scratcher type of events," said Dr Peter Nugent. "At first we thought it was completely normal and boring. Then it just kept staying bright, and not changing, for month after month. I would really like to find another one like this."

Supernovae are supposed to only happen once, but try telling iPTF14hls that

THE DOWNLOAD

W Hydrae

What's that? The multi-headed serpent killed by Heracles?
Nope. It's a red giant star, located 320 light-years from Earth in the constellation of Hydra, that was recently observed in unprecedented detail by researchers at the ALMA Observatory in Chile.

What's special about it?
When it started life, W Hydrae had a very similar mass to the Sun, making it an ideal subject to study to learn more about the ultimate fate of our Solar System's own star.

Tell me more!
Stars like the Sun age over many billions of years. As they reach old age they swell up, becoming larger and cooler as they grow, and losing mass thanks to the action of solar winds. During this stage, they release elements for the formation of new stars and even life, such as carbon and nitrogen, into space.

Currently, W Hydrae is around twice the size of the Earth's orbit around the Sun.

So what's next?
The team plan to take further, more accurate, images in order to study how the processes change as the star ages.

The teeth found in Devon came from two small, rat-like mammal species that co-existed with dinosaurs

PALAEONTOLOGY

TEETH SHED NEW LIGHT ON MAN'S EARLIEST ORIGINS

Two fossilised teeth found on Devon's 'Jurassic coast' have been identified as belonging to some of man's earliest ancestors.

The teeth belonged to two previously unknown species of small, rat-like creature that lived around 145 million years ago, during the Early Cretaceous period. The two species, which have been named *Durlstotherim newmani* and *Durlstotherim ensomi*, are now effectively the earliest known creatures in the line that led not just to humans, but to pretty much all mammals that are alive today – from the tiny pygmy shrew to the giant blue whale.

The fossilised teeth were discovered by Grant Smith, an undergraduate student at the University of Portsmouth. After realising they were the teeth of some kind of early mammal and showed them to his supervisor, Prof Dave Martill, who, excited by the find, consulted Dr Steve Sweetman, an expert in early mammals, who confirmed the specimens' remarkable age.

"Even at first glance my jaw dropped. The teeth are of a type so highly evolved that I realised straight away I was looking at remains of Early Cretaceous mammals that more closely resembled those that lived during the latest Cretaceous – some 60 million years later in geological history," said Dr Sweetman. "Our 145 million-year-old teeth are undoubtedly the earliest yet known from the line of mammals that lead to our own species."

The creatures from which the teeth came would have been small, burrowing mammals, and most likely nocturnal.

"The teeth are very worn, which suggests the animals to which they belonged lived to a good age for their species," said Dr Sweetman. "No mean feat when you're sharing your habitat with predatory dinosaurs!"

THINGS WE LEARNED THIS MONTH

BLUE LIGHT CAN HELP TO RELAX US FOLLOWING AN ARGUMENT

If you find your blood boiling after a bit of argy-bargy, get yourself a blue light. A team at the University of Granada has found that blue lighting can help us to calm down.

DOGS ARE RED/GREEN COLOUR BLIND

Thinking about playing fetch with your dog in the park? You might want to think twice before buying a red ball: researchers at the University of Bari, Italy, have found that dogs can't distinguish between the colours red and green.

EATING MUSHROOMS COULD HELP US LIVE A LONGER, HEALTHIER LIFE

High levels of the antioxidants ergothioneine and glutathione found in mushrooms could help to prevent cell damage caused by free radicals – oxygen atoms with unpaired electrons produced when the body uses food to produce energy.

CATS COULD PREVENT CHILDREN GETTING ASTHMA

Danish researchers have found children who grow up in families that keep pet cats are far less likely to suffer from asthma. The effect is thought to be down to specific genetic triggers for the conditions being switched off when children are in regular contact with moggies.

PHOTO: DR MARK WITTON/UNIVERSITY OF PORTSMOUTH

INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

CHRISTMAS 2017 EDITED BY RUSSELL DEEKS

Pimax's new VR system raises the graphics bar with 8K resolution

GAMECHANGERS

As the year draws to a close, we take a look back at the tech and gadgets that left a mark in 2017...

First up are two virtual reality headsets that highlight how rapidly VR is evolving. Consumer VR has so far mostly come in two flavours. Either you wear a costly headset connected to an even more expensive PC/Mac, or you tuck your phone into a visor, which is less immersive but a lot cheaper. But now there's Oculus Go, a standalone dedicated VR headset and handheld controller that require no other hardware – giving you the best of both worlds for just $199 (£150 approx).

Meanwhile, a new headset from Japanese start-up Pimax VR recently broke the Kickstarter funding record previously held by Oculus Rift. Their headset promises unparalled immersion, with each eye treated to its own 4K display.

But while VR has been big news in 2017, it wasn't the only technology to be developing apace. So over the next eight pages, we look at some of the hottest topics in tech in 2017, from robots to AI to electric cars, and ask, 'Where next?'. The future starts here...

1 TWO SCREENS BETTER

Taking its design cues from hybrid portables, ZTE's latest smartphone features a hinged body and *two* 5.2-inch screens. You can have one screen mirror the other, multi-task in two different apps or combine the two into one large display.

ZTE Axon M

£500 approx (tbc), ztedevices.co.uk

2 AIBO RETURNS

Sony's robot dog was an instant hit in 1999, and went on to sell over 150,000 units. And now it's back – with improved robotic movement, enhanced 21st Century AI smarts and a camera in its nose. It goes on sale in Japan from January.

Sony Aibo

¥198,000 (£1,300 approx), sony.co.jp

3 SCREEN ENVY

This is the only TV that makes us a little weak at the knees. The OLED display means there's no need for backlighting, making it thinner, lighter and more visually accurate than most. Weighing in at 7.7kg the TV it can be mounted on magnets.

LG Signature OLED TV W

£6,999, lg.com

4 X MARKS THE SPOT

This is the first iPhone we've been excited about in a long time. There's not actually a lot of new tech here, but it's the way it's been put together. The edge-to-edge OLED display, True Depth Camera and slick interface make it feel like the phone of the future.

iPhone X, From £999, apple.com

5 TREAT YOUR EARS

The earphone to rule all earphones, these in-ears feature ultra-thin drivers, a magnesium body and a silver-coated copper cable braided in Kevlar. They sound like nothing else – just don't drop them in the washing machine.

Audeze LCDi4

$2,495 (£1,880 approx), audeze.com

6 SMALL BOX, BIG SOUND

Sky's Soundbox features nine drivers that bounce sound off nearby walls to create a 3D soundstage. There are also some nifty EQ options such as Q Sound, which adjusts the sound output based on metadata in the TV stream.

Sky Soundbox

£299 (Sky subscribers)/£799, sky.com

7 SWITCH IT UP

Nintendo made consoles fun again. The switch is a design masterclass. Its portability means you can squeeze in game time wherever you are, and it's simple control system lets you get all your friends and family involved. We want one.

Nintendo Switch

£279, store.nintendo.co.uk

8 PARALLEL PODDING

Plug in these pods around your house to optimise your wi-fi network's bandwidth and range. Stream Netflix in one room and YouTube in another, and the system will shuffle your data around the plugs to create capacity for both.

Plume Wi-Fi, £179, plumewifi.com

9 CUSTOM CANS

Nuraphone's eponymous headphones feature both an in-ear bud and an over-ear cup, and are tuned to your hearing by means of some arcane wizardry called 'otoacoustic profiling'. *Focus* editor Dan says they're among the best headphones he's ever heard.

Nuraphones

£349, uk.nuraphone.com

10 BRIGHT SPARK

The compact and bijou Spark may be one of DJI's tiniest drones to date, but it packs the same AI obstacle avoidance and gesture control as its bigger brothers – and it's a tad more affordale. The drone age is officially here.

DJI Spark

£519, dji.com

11 GIRLS ON TOP

At time of writing, this Lego set paying tribute to female pioneers of space exploration was the No 1 best-selling toy on Amazon. The set includes four minifigures, plus tiny versions of the space shuttle and the Hubble Space Telescope.

Lego Women Of NASA

£20, shop.lego.com

12 OUT OF THIS WORLD

The iPhone X grabbed the headlines, but Samsung's latest Galaxy phone offers very similar specs for a whopping £300 less. With Google's Pixel 2 phone also just landed, the high-end smartphone market remains highly competitive.

Samsung Galaxy S8

From £689, samsung.com

TRANSPORT

PETROL AND DIESEL CARS GET AN EVICTION DATE

Plug-In Adventures' modified Nissan Leaf was the first electric vehicle to complete the 12,875km Mongol Rally

Dirty air is making us ill. In fact, 40,000 premature deaths per year can be attributed to poor air quality, according to the Royal College of Physicians. So news in July that the government was setting out to clean up our air was welcome. The headline was that the sale of petrol and diesel cars and vans would be banned by 2040 – with hybrids being exempt.

But the initiative was greeted by a healthy dose of scepticism. Firstly, climate and environment experts felt the deadline wasn't soon enough: we'll still be breathing in polluted air for the next 22 years. Secondly, the scheme didn't explain how the country might prepare for a new influx of cars needing somewhere to plug in. To cope with the extra energy demand, it's estimated we'd need 30GW of extra electricity per year, equivalent to the output of 10 more Hinkley nuclear power stations or 10,000 more wind turbines. Finally, the RAC pointed out that it wasn't clear what the ban meant for drivers, with big cities likely to start imposing their own restrictions on polluting vehicles much sooner.

There is cause for optimism, though. While the infrastructure strategy is lacking, car makers from Nissan to Volvo to Jaguar are competing to reimagine themselves in an emissions-free age. Nissan, which produced the Leaf – the first proper electric car – sent it to compete in the Mongol Rally, proving that you don't need fossil fuels to go long haul. It also unveiled home charging stations which could store power from the grid at off-peak hours, to lower costs. Dyson announced plans to build an electric car in the near future, while Tesla recently answered the question "What about trucks?" with its Electric Semi, which can haul 36 tonnes for 500 miles on a single charge.

Car makers are competing to reimagine themselves in an emissions-free age

SMART HOMES

ALEXA USHERS IN THE INTERNET OF THINGS

Focus's year in tech started at the CES show in Las Vegas, where Amazon's voice assistant Alexa could be found in over 30 products. That trend continued all year, with new Alexa devices hitting the shelves almost daily, and Amazon itself recently unveiling a raft of new Alexa products including Echo Spot, Echo Connect and, most significantly, Echo Plus, which doubles as a fully-fledged smart home hub.

With Alexa now in so many homes, this is an obvious next step. When tech companies first started talking about 'internet fridges' and other Internet of Things (IoT) devices, people laughed: who needed to go online or fumble about in an app to see if they had milk, when they could just open the fridge door? But introduce Alexa to the mix, and suddenly you can check if you've got milk, and order more if you haven't, without even reaching for your phone.

So expect 2018 to be the year when the IoT – Now With Voice Control!™ – finally takes off. But at what price? Almost as frequent as Alexa product launches in 2017 were alerts about security weaknesses in IoT devices – from the Amazon Echo, to Nest security cameras, to children's toys and smartwatches aimed at kids, which Germany has just gone so far as to ban outright. In May, Daniel Coats, the US Director of National Intelligence, suggested insecure IoT devices could be used to launch cyberattacks on vital infrastructure, while a recent report by German security specialists Gemalto found that just 52 per cent of data captured by such devices is encrypted.

John Moor, managing director of the IoT Security Foundation, told *Focus*: "At this point in time there are no specific regulations for IoT security, and that explains in part why we are seeing so many problems. But we're starting to sense a consensus form around the key requirements for IoT security, and we are encouraging governments considering regulation to look hard at our expert-led work, so as to translate this into useful regulation for responsible suppliers, consumers and citizens."

Alexa is everywhere – most recently, in (clockwise) the Amazon Echo Plus, Echo, Echo Connect and Echo Spot

ARTIFICIAL INTELLIGENCE

AI BEATS PUNY HUMANS

As Elon Musk and Stephen Hawking issue stark warnings about the singularity, Garry Kasparov says we should stop worrying and learn to love the all-knowing machine brain

PHOTO: **DEEP DREAM GENERATOR**

Former chess grandmaster Garry Kasparov was famously beaten by an AI system, but now he's a firm advocate of the technology

If Artificial Intelligence (AI) were truly smart, it would hire a good PR. For a start, we're not really sure what AI is, which complicates our every conversation about what effect it will have on our lives. We can't even really agree on what intelligence is in humans, where the conversation inevitably veers away from science and into philosophy.

As neither a scientist nor a philosopher, but with decades of personal experience on the front lines of both human and machine cognition, I prefer to focus on the practical. AI will be the greatest technological advance since the internet turned the world into a living stream of data. It will be more subtle, more all-encompassing, and eventually more transformative than the web, changing every part of our lives in seen and unseen ways. And it's already happening.

After many recent conversations with AI luminaries such as Demis Hassabis, of Google's DeepMind in London, and legendary technologist Ray Kurzweil, also now at Google in California, the idea that I feel is most important to communicate to my audiences is that artificial intelligence is not a monolithic thing. Inevitably, most of the attention goes to the tangible products of AI: the driverless cars, the smartphone assistants and, for better or worse, the chess-playing machines. Meanwhile, there are countless algorithms that are getting a little smarter each day, a billion lines of code that are improving themselves with machine learning processes.

From medical diagnosis to investment banking, from hiring staff to educating our children, these increasingly capable systems are changing the world. These intelligent agents are the only way to sift through the oceans of data we are producing at an exponential rate, revealing the hidden patterns and insights into how the world, our bodies and our minds work.

Whether you find this terrifying or wonderful is important, because public sentiment drives education, investment, and regulation, making the outcome a type of self-fulfilling prophecy. That is, if people find the rapid advance of intelligent machines terrifying instead of wonderful it won't stop it, but it could make the outcome much worse. Powerful new tech always disrupts and nearly always causes distress before producing broad benefits. By slowing down our progress out of unreasoning fear, we prolong the distress phase by delaying the next waves of breakthroughs needed to produce the broader benefits.

"I'm glad that great minds like Stephen Hawking and Elon Musk are voicing their concerns"

There are real and immediate concerns about the proliferation of intelligent machines, especially autonomous ones. Rising inequality if automation hits lower-income people harder; transparency and accountability of the algorithms; personal data being hoarded and abused by private companies or repressive regimes. None of these issues come anywhere close to an existential threat – the killer robots of Hollywood or the super-intelligent AI that sees no reason to keep humans around. It's as if instead of racing ahead with spreading the light and power of the modern world a century ago, everyone instead obsessed about how we might all one day be electrocuted.

As a member of the executive board of the Foundation for Responsible Robotics and as a security ambassador for Avast Software, I've become all too familiar with the real threats AI-enhanced machines may pose. And I'm glad that great minds like Stephen Hawking and Elon Musk are voicing their concerns, and that top AI authorities like Nick Bostrom are mapping out the worst-case scenarios. After all, we live with nuclear power that could literally destroy the planet, and we certainly want it to be monitored and used responsibly.

But like all our inventions, AI is agnostic: capable of being used for good or evil. Morality matters, and so making better humans will always be more important than making smarter machines. Above all, we must keep moving forward, because the only solution for the problems caused by today's technology is tomorrow's.

Former world chess champion **Garry Kasparov** is the author of *Deep Thinking: Where Machine Intelligence Ends And Human Creativity Begins* (John Murray, 2017). He is the chairman of the New York-based Human Rights Foundation and a Senior Visiting Fellow at Oxford Martin.

STRANGER THINGS

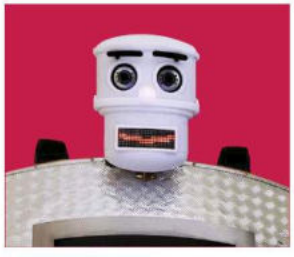
2017 has been a weird year all round, and it was no different in the world of technology. Here's our pick of the year's tech oddities...

BICKERING BOTS

In January, an unidentified evil genius set two Google Home chatbots up to talk to each other and thousands of users of Twitch – the live videostreaming channel where people watch each other play games – tuned in to watch. Their rambling, surreal conversation touched on Toronto, the Super Bowl and polar bears, as each tried hard to convince the other it was a real life human being.

ROBOT VICAR

In May, a church in Wittenberg, Germany took delivery of a vaguely humanoid robot called Bless U-2. When you pressed a touchscreen in the robot's chest, its arms raised up and its computer-animated mouth offered up a blessing in German, English, Polish, Spanish or French. Sadly, though, it was only in the church for a short time, as part of an exhibition marking the 500th anniversary of the Reformation.



SONIC ATTACK

The weirdest tech story of the year surrounded the US embassy in Cuba. Since August, diplomats and their families have reported hearing strange, piercing noises that caused them problems afterwards with memory, hearing and speech. Various theories have been put forward – from a mysterious sonic weapon to mass hysteria – but a conclusive explanation has yet to emerge...

FAR OUT

Ever fancied becoming a citizen of space? In June, virtual nation Asgardia, which was set up in 2016 and has over 100,000 registered citizens, announced plans to launch a satellite into space in association with commercial satellite providers NanoRacks. Asgardia's long-term plan is to build a manned colony in orbit, and at time of writing, the late November cubesat launch was still due to go ahead.

SUB MISSION

In September, the US Navy announced it was scrapping the £30K joystick Lockheed Martin had developed for its new Virginia class submarines, and using an Xbox controller instead. They do the job just as well, need no special training and you can pick up a spare for £30 anywhere in the world.

PEAK DULL

Got five minutes to kill? Or five hours? Then check out June's surprise hit browser game *It Is As If You Were Doing Work*, which lets you experience/relive [delete according to age] all the 'thrills' of doing clerical work on a 90s Windows PC. If you want to try it for yourself, head over to **bit.ly/itisasif**.

FLYING SQUAD

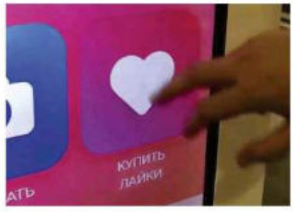
With robot patrol cars already on the streets, Dubai leads the world in high-tech policing right now. But credit, too, to Devon & Cornwall Constabulary, who this summer became the first force anywhere in the world to have a dedicated drone squad working 24 hours a day. Among other duties, the UAVs are used to search for missing persons, in coastal rescue missions and to monitor road traffic accidents.

ROBOT NIRVANA

Anything Lutherans can do, Buddhists can do better, as the old song goes. At a tech show in Japan in August, a company called Nissei Eco was showing off a Pepper robot (built by Aldebaran) that it had customised to conduct Buddhist funerals. Unlike Bless U-2, this was a real product – though whether anyone was actually buying remains unclear.

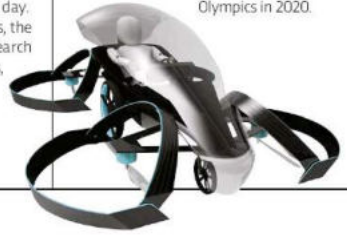
FAKE FANS FOR SALE

In July, outraged reports started coming in from Russia about some strange new vending machines. So what were they selling to cause uproar: sugar-laden fizzy drinks and chocolate? Cancer-causing cigarettes? Illegal drugs? Worn undergarments? Nope: Instagram likes, with 100 likes costing about 70p.



UP, UP & AWAY!

In May, Toyota announced it was developing a new car. Nothing unusual about that – except that this one's a flying car. Toyota has thrown its weight behind Cartivator, a start-up based at Japan's Tokushima University that's developing a flying car called SkyDrive which it hopes will be ready in time to be a torch-bearer at the opening of the Tokyo Olympics in 2020.



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UNLOCKING THE SECRETS OF THE BRAIN

From autism and schizophrenia to Alzheimer's, lab-grown mini-brains could be the key to solving the biggest mysteries about human development and disease

WORDS: SIMON CROMPTON

ILLUSTRATION: MAGIC TORCH

Stacks of little plastic dishes in a laboratory incubator, each one holding a free-floating blob of human brain might sound like the stuff of science fiction. But this is no futuristic flight of the imagination: these strange creations, known as brain organoids, are already being cultivated in labs all over the world, and researchers believe they could unlock some of the deepest secrets of how our brains grow and what happens when they go wrong.

"I don't think that any of us set out to try and grow a brain in a dish," says Madeline Lancaster, a neurobiologist at the MRC Laboratory of Molecular Biology in Cambridge. "If you'd asked me even just a few months before I started working on it, I would have said it was completely nuts – but in my case, it was an accident!"

Lancaster's accidental experiments with organoids started when she was a postdoctoral researcher working in Vienna with molecular biologist Jürgen Knoblich, investigating how the brain forms during development in the womb. She started by growing brain stem cells in flat layers in a dish, but soon realised they lacked many of the key characteristics of nerve cells in a real brain. In search of a better method she tried a new technique for growing neural 'rosettes' – flat, flower-like circles of cells that were more realistic, albeit still two-dimensional.

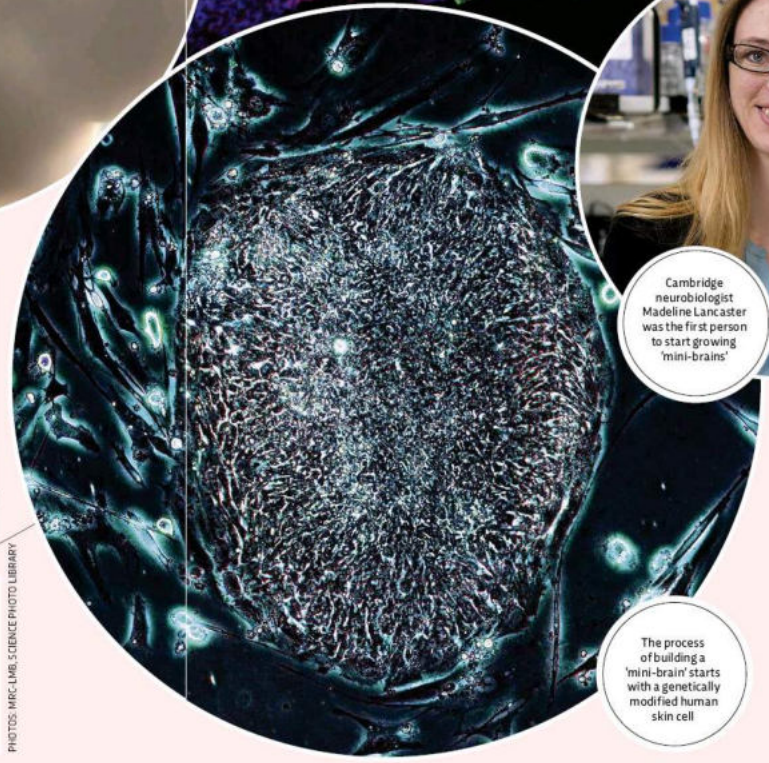
"When I put the cells in the culture dish, there was something wrong with the reagents that I was using," she says. "Rather than forming these nice flat rosettes, mine were forming these weird, floating balls. I thought they looked interesting, so I continued growing them."

Speaking to other researchers in the field, she discovered that some of them had also seen these strange blobs, but had thrown them away because they looked wrong. But while these brain balls looked curious from the outside, what Lancaster found inside was fascinating. Each was made from bulging layers of cells connected by cavities, just like the fluid-filled ventricles that connect the hemispheres of the cerebral cortex in a real brain. Even the layers of cells mimicked the arrangement in normal brain tissue, with stem cells lining the ventricles and layers upon layers of more specialised cells and neurons built up towards the outside.

One of Madeline Lancaster's cerebral organoids, seen here in cross-section

A bright-field microscopic image of a cerebral organoid. In real life, this 'mini-brain' is 1cm across

Cambridge neurobiologist Madeline Lancaster was the first person to start growing 'mini-brains'



The process of building a 'mini-brain' starts with a genetically modified human skin cell

PHOTOS: MRC-LMB, SCIENCE PHOTO LIBRARY

BUILDING A BRAIN

Despite their 'mini-brain' nickname, these organoids are a long way from being full-size human organs. They're around half a centimetre in diameter – roughly the shape and size of the eraser on the end of a pencil – and they lack key structures such as blood vessels, which limits how big they can grow.

"Despite their 'mini-brain' nickname, these organoids are a long way from being full-size human organs"

Organoids are also remarkably hardy, as long as they're grown in a scrupulously clean environment, and can stay alive for more than a year. Lancaster's mini-brains are enabling her to prise open the 'black box' of human brain development. Because they reflect the cell types and organisation of a growing human brain, organoids are opening a window into time of life that has previously been inaccessible to science.

"People have done MRI scanning on children and even babies to and look how the brain wiring changes, but when it comes to those early events – how neurons are made, how many, which types and where – we can't answer them, no matter how good our MRI machine is. But I think what's happening in these dishes reflects what's happening in an actual embryo. We know this because the end product looks like a lot like a real brain, so we have a tractable system to start asking some of these fundamental questions about brain development."

Lancaster is also using her mini-brains to answer an even deeper question: what makes a human brain human? We share more than 95 per cent of our DNA with our closest primate relatives, such as chimpanzees, but our brains are much bigger and undoubtedly different. By comparing brain organoids grown from chimp stem cells with those from humans, she and her team are watching how these differences emerge from the earliest stages of development. There's even the possibility of using new genetic engineering techniques to switch human and chimp genes around in mini-brains – something that would be impossible to do in living animals – to pin down the precise molecular pathways that make the human brain so special.

The brain-like appearance of these organoids raises ethical as well as scientific questions. Can they think, and are they conscious? According to Lancaster, the answer is almost certainly no. "I think of them as being a bit like brain tumours," she says. "Tumours contain many more neurons than our mini-brains in a dish, but no one is concerned that their brain tumour is thinking or has consciousness, and nobody is sad that it has been taken out and thrown away. That's what we have here. It's not an organised network, and it cannot make a functional thinking circuit – it's a ball of brain tissue, and just because you have neurons doesn't mean it can think."

Today, she and her team are growing mini-brains from human embryonic stem cell lines – the multi-purpose cells originally found in very early human embryos, but now cultivated in the lab. She's also using so-called induced pluripotent stem (IPS) cells: adult cells that have been pushed back to an embryonic state with a cocktail of molecules first discovered by Nobel Prize-winning Japanese scientist Shinya Yamanaka. Depending on the exact conditions used, Lancaster can nudge her organoids to develop all kinds of cells, from the fluffy choroid plexus (which would connect with blood vessels in a real brain) to pigmented light-sensing cells that are usually found in the retina at the back of the eye.

"There's just so many cell types to look for," she says, "But depending on the method we use, every time we look for something that we know should be there, we find it."

WIRING UP

Mini-brains don't just allow researchers to study normal developmental processes. Sergiu Pasca, Assistant Professor of Psychiatry and Behavioural Sciences at Stanford University in California, is using them to understand what goes wrong in autism, schizophrenia, epilepsy and other neuropsychiatric disorders.

"Most of the psychiatric drugs we have today have been discovered by chance – we know very little about the origins of these disorders and the question is why?," he asks. "Unlike cancer biologists, who can take out a tumour, put it in a dish and find ways to treat it, we cannot do that with the brains of our patients with mental disorders!"

Pasca and his team have managed to grow mini-brains for more than two years – a staggering 800 days is their current record – and shown that they can generate most of the same cell types and structures found in real human brains. They're using the technique to investigate the roots of severe autism and epilepsy syndromes, by generating organoids with IPS cells derived from skin samples of affected children and then carefully comparing them with cultures grown from healthy cells.

"We can use electrodes to measure how the cells are talking to each other, and microscopy to see how the cells move and make connections with each other," he explains. "Many of the genes associated with these disorders are involved in the connections between nerve cells, so we can see how the gene changes in these patients are impairing the communication within the brain in a non-invasive way."

He's now taking these ideas even further, sticking together organoids that mimic different regions of the brain and studying their interactions – a technique he describes as 'brain Lego'. The team is using these hybrids to spy on the brain as it wires itself up, focusing on what happens to so-called inhibitory neurons that normally help to calm down brain activity but are faulty in people with epilepsy and autism.

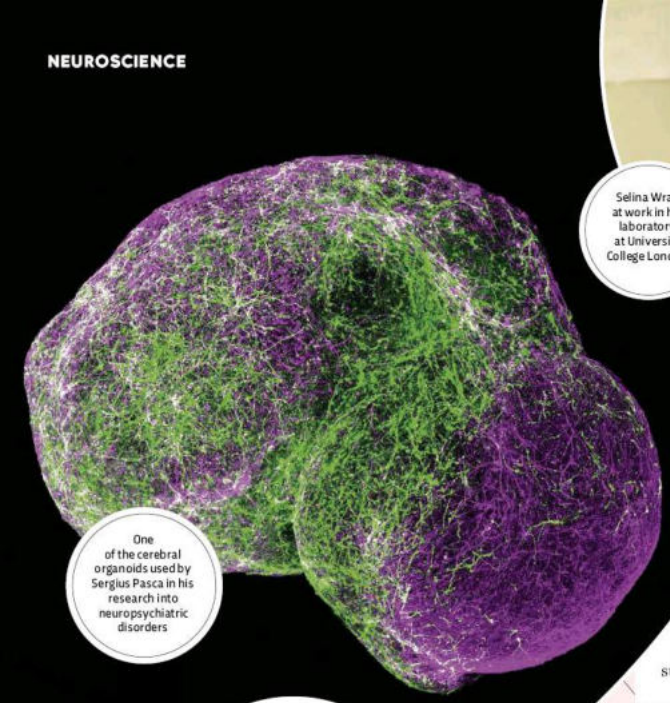
"Inhibitory neurons are not born in the cortex on the surface of the brain: they are born in a very deep region of the forebrain and have to migrate millimetres over many months after birth," Pasca says. "It's really fascinating to watch in our cultures – they kind of pull themselves up and jump along."

But when Pasca and his colleagues looked at organoids grown using cells from patients with a

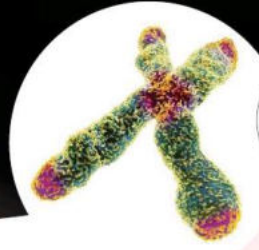
"Pasca and his team have managed to grow mini-brains for more than two years – a staggering 800 days is their current record"

Sergiu Pasca holding 'mini-brains' used to study the development of conditions such as autism

PHOTO: SHUTTERSTOCK



One of the cerebral organoids used by Sergius Pasca in his research into neuropsychiatric disorders



An X chromosome: the red areas at the end of the 'arms' are telomeres, which play a role in ageing

Selina Wray at work in her laboratory at University College London

PHOTOS: UCLA, SCIENCE PHOTO LIBRARY; CHARLIE ARBER & CHRIS LOVEJOY/UCL

form of autism that is associated with epilepsy, they saw a very different picture. The inhibitory cells were moving in a very peculiar way, jumping more often but less efficiently and eventually getting left behind.

Impressively, the researchers were then able to identify a drug that could rescue these lagging cells, correcting the wiring defect and pointing towards a potential future treatment for children suffering from the same condition.

INTO OLD AGE

Meanwhile at University College London, neurologist Selina Wray is using brain organoids to look at neurodegenerative conditions that start at the other end of life, including Alzheimer's disease and fronto-temporal dementia.

"Normally we have to work with post-mortem brain tissue from patients, but you're only ever looking at the end stages," she says. "It's almost like coming to the scene of a crime after the criminal is gone, and you're trying to piece together a sequence of events by looking at the damage that's been left. I want to build models in the lab which will let us look at the very beginning of the disease – because if we understand the first things to go wrong, that's when treatment should be more effective."

In a similar way to Pasca and Lancaster, she's taking samples of skin from patients with dementia, turning them into IPS cells and then growing organoids. Wray can spot differences compared with organoids from unaffected people after just a few months, finding increased levels of the forms of certain molecules that are associated with Alzheimer's disease.

However, there's a problem with this approach: mini-brains mimic the very earliest stages of life, while dementia is a problem that takes decades to develop. To solve this, researchers are working on clever hacks to speed up the ageing process. One idea is to add in genetic changes that mimic progeria – a rare disorder that causes dramatic premature ageing. Another approach is to meddle with the structures protecting the ends of DNA inside cells, known as telomeres, which act as a kind of countdown clock as we age.

As well as studying the underlying processes that drive dementia, Wray thinks that mini-brains have a lot of potential for helping to identify the right treatment for individual patients.

"I feel excited by the idea of personalised medicine – that you could take somebody's cells and grow organoids in the lab, screen a panel of drugs against them and say, 'Okay, we think this person will respond to drugs ABC, but this person will respond better to drugs XYZ,'" she says. "That's happening in cancer biology, this idea of being able to stratify patients on a molecular basis, and while I think we are a long way off, I love the idea of growing someone's neurons so we can work out what therapies we should be giving them."

Sergiu Pasca is similarly enthusiastic about the potential of mini-brains to change lives.

"Our organoids are grown from cells taken from real patients," he says. "These kids have severe neurodevelopmental disorders that really impair their lives, and to think that a few months later you can derive brain tissue from those patients in a dish and start asking questions about how the disease may arise – that's what makes this exciting."

"Mini-brains mimic the very earliest stages of life, while dementia is a problem that takes decades to develop"

Kat Arney is a science writer and broadcaster. Her latest book is *How To Code A Human*. She tweets from @Kat_Arney

ALL THE ORGANOIDS

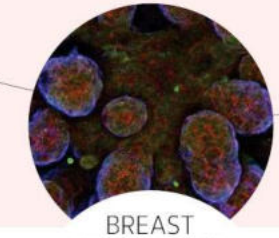
It's not just brains: researchers are creating three-dimensional organoids from many different types of tissue, not only to study healthy development but also to discover what happens when things go wrong and to develop future therapies. Here are some of the types they've managed to grow so far...

GUT

Scientists have made organoid versions of many parts of the gastro-intestinal tract, from taste buds to the intestines and stomach. Intestinal organoids can be manipulated to produce insulin, suggesting possible future treatments for diabetes.

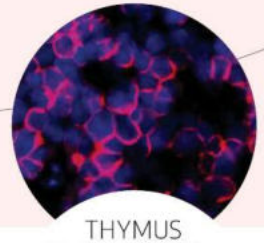
LUNG

Although they're a long way from a 'lung in the lab', lung organoids grown using reprogrammed stem cells from patients with diseases such as chronic asthma and cystic fibrosis could be useful models for finding new treatments.



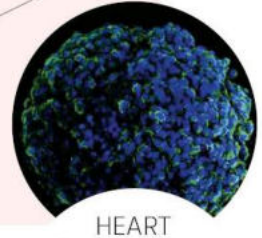
BREAST

Mammary organoids grow the same branching structures that are seen in human milk ducts. Because many breast cancers start from such ducts, these organoids are providing vital insights into tumour growth.



THYMUS

The thymus gland is the place where infection-fighting immune T-cells mature. Thymus organoids can produce functional human T-cells, which could potentially be used to restore the immune system in transplant patients.



HEART

Cardiac organoids are revealing hidden regenerative pathways that could be reactivated to treat heart disease. Researchers also created organoids with functional, beating chambers, as a model for studying heart failure.

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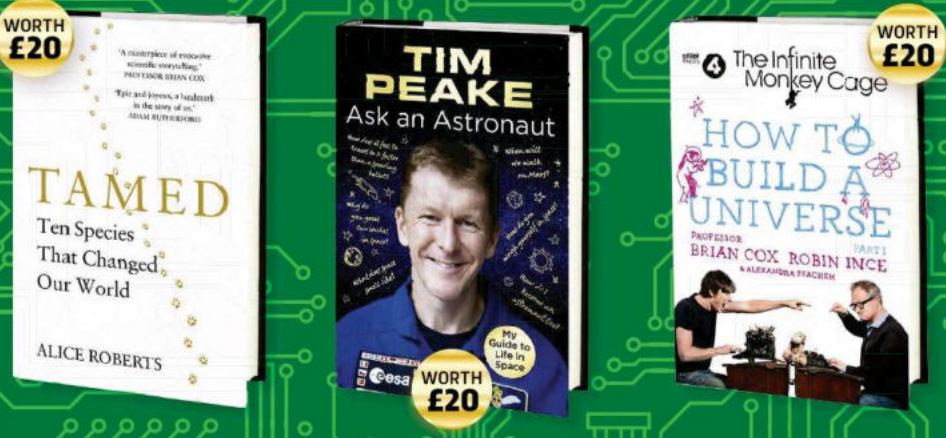

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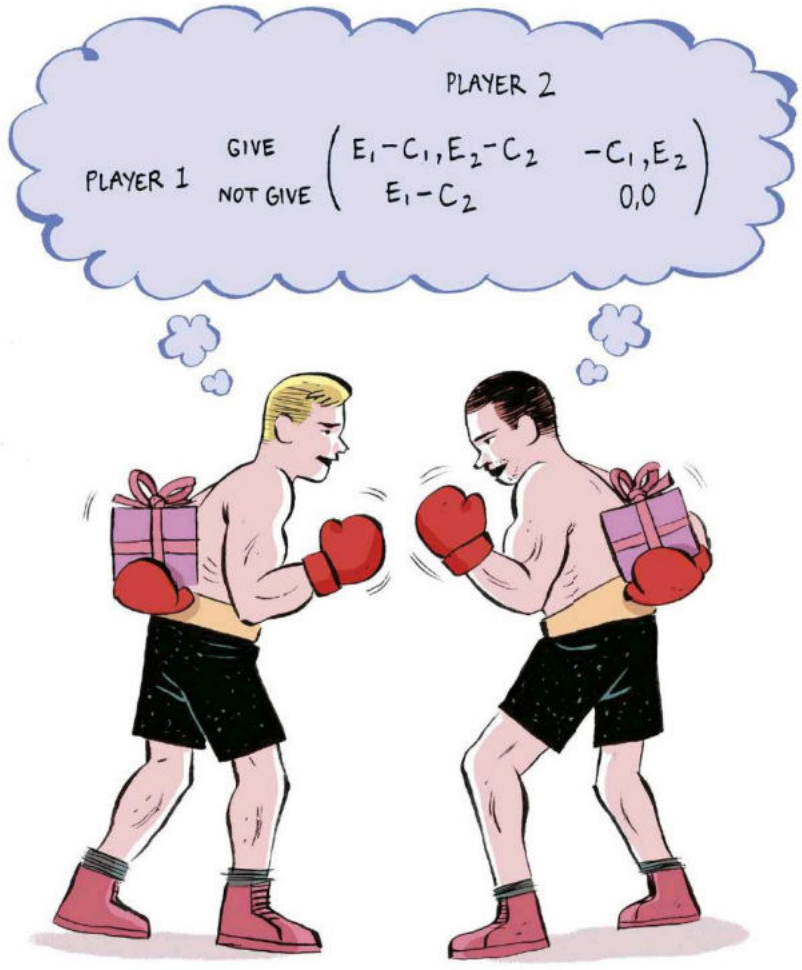
SCIENCE HACKS FOR

A PERFECT CHRISTMAS

Use the power of science to make 2017 the best Christmas ever

WORDS: **PAUL PARSONS**



HOW TO
GO CHRISTMAS SHOPPING

You have a long list of family and friends, but only limited funds in the bank. Who should you buy presents for?

Prof Rachel Norman and Dr Anthony O'Hare, at the University of Stirling, have applied game theory to the exchange of gifts. Game theory is a branch of maths to do with calculating optimal strategies in competitive situations. Central to it is the idea of finding the unexploitable 'Nash equilibrium'. If two people are both playing the Nash strategy, then neither can improve their lot by changing tack.

Let's say receiving a present invokes enjoyment, E, but giving incurs cost, C. The diagram above shows the possible payoffs for two people. For example, if player 1 gives but player 2 doesn't then player 1 gets -C_1 (a net cost) while player 2 has no cost but gets enjoyment E_2.

The Nash equilibrium here is for both players to not give. The payoff for each is then zero – and if either one deviates unilaterally they become worse off.

This assumes that the 'game' is only played once. American political scientist Robert Axelrod has shown that when games are played many times, greedy strategies like this are no longer optimal. Instead, the best payoff comes from a 'tit-for-tat' approach – buying a present on the first Christmas and then, in subsequent years, copying what the other person did last time.

ALL ILLUSTRATIONS: JAMIE COE

HOW TO
CUT A CHRISTMAS CAKE

If you're tired of forcing down dried up Christmas cake in March, then the good news is science has found a simple way to keep cake fresher for longer.

In a letter to the research journal *Nature*, published on 20 December 1906, the great British polymath Sir Francis Galton opined that the traditional way of cutting a Christmas cake was "very faulty". He argued that taking a wedge out at a time leaves the inside surface of the cake exposed and liable to get dry. Instead, Galton advocated a novel method of cake slicing that involves making parallel cuts through the centre of the cake and then closing it up and securing with an elastic band to lock in the freshness.

This is shown in the diagram, adapted from a sketch that accompanied Galton's original letter. Solid lines show existing cuts; dotted lines show the next cut to make. The first cut, shown on the left, removes a flat slice and the cake is then closed up into an oval shape and stored. The next slice is removed in a similar fashion but at 90 degrees to the first cut, as shown in the centre image. The next slice would be taken parallel to the first cut and so on.

"The method works," says maths writer Alex Bellos. "I have done it many times."

HOW TO
COOK THE TURKEY

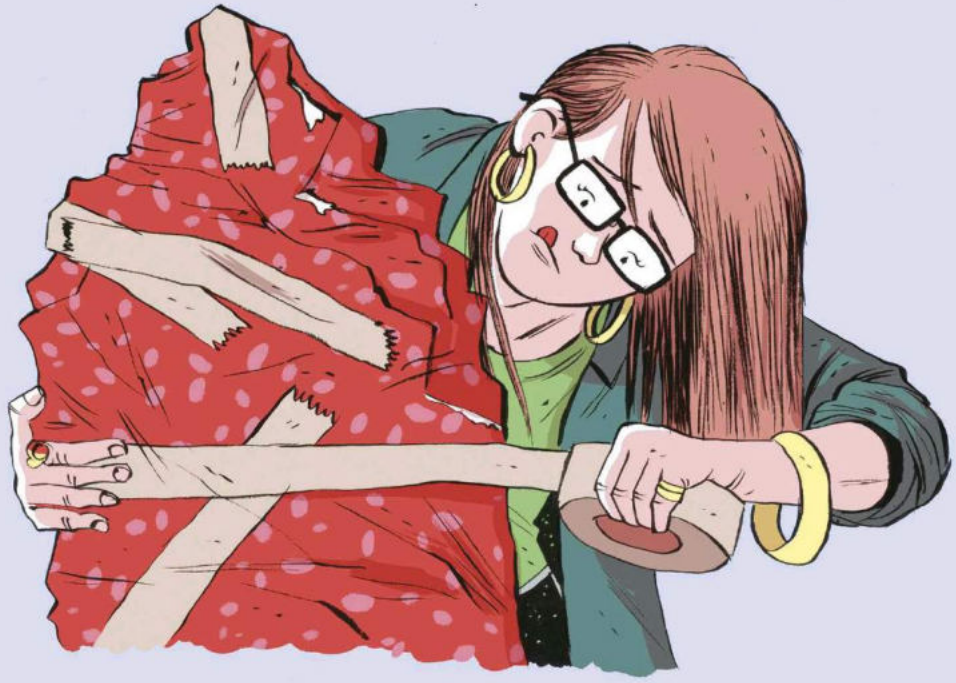
What makes the perfect Christmas turkey?

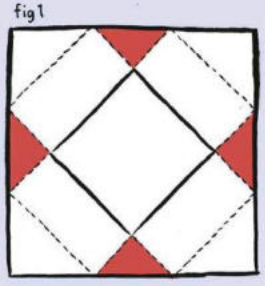
Roasting a turkey is tricky because the meat is made up of different components that all, ideally, require cooking at different temperatures. For example, the breast meat shouldn't be heated much above 55°C, to prevent it becoming too tough – whereas the darker leg meat needs to reach at least 80°C and the skin requires as much as 200°C to trigger the Maillard reactions that brown the outside and create the characteristic flavour.

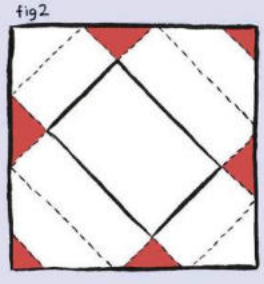
Prof Peter Barham, a gastronomically inclined physicist at the University of Bristol, says the ideal strategy is to chop up the turkey and cook each part separately at its optimum temperature. In case a heap of slivered turkey flesh isn't quite the table centrepiece you were hoping for, he suggests cladding the more sensitive parts in foil for the bulk of the roasting time.

But how long should that time be? The late Stanford University physicist Wolfgang Panofsky used the laws of heat conduction to come up with the formula $t = 1.13 \times W^{(2/3)}$ where t is the cooking time in hours and W is the weight of the turkey in kilograms. He assumed an oven temperature of 165°C (325°F) – and a spherical turkey.

For safety, it's recommended to use a meat thermometer and ensure the inside of the bird is cooked to at least 75°C. Bon appetit!







HOW TO
WRAP YOUR PRESENTS

Dr Sara Santos, of Goldsmiths, University of London, has devised a formula to calculate the optimal dimensions of wrapping paper to cover a cuboid box.

For a square-based box, you need a square of paper with side length equal to the base diagonal of the box plus 1.5 times its height. Place the box on the paper at 45 degrees, bring the corners of the paper up to meet at the top of the box and secure with a single piece of tape (fig 1). For a rectangular base, use a square of paper with side length equal to the width of the box plus its length plus twice its height, all multiplied by 0.75 (fig 2).

That said, Drs Hannah Fry and Thomas P Oléron Evans, in their book *The Indisputable Existence of Santa Claus*, argue that this technique uses no less paper than the traditional method – though it does look nice, and saves tape. They suggest a more practical approach is to use flatter boxes to minimise the paper wasted in flaps tucked in at the ends of the present. A box half as high as its base side length takes 11 per cent less paper than a cube of the same volume.

Taken to the limit, this means you should give totally flat presents – another reason to treat your nearest and dearest to copies of *Focus*!

HOW TO
RUN A SECRET SANTA

In the office game of Secret Santa, people write their names on pieces of paper, put them in hat and then each draw one random person to buy a gift for. If anyone gets their own name, they replace it and draw again.

But this breaks down if the last person to draw picks their own name – in this case, to maintain anonymity, the only thing you can do is start over. And in an office of 10 people, this happens over 7.5 per cent of the time. It's also not perfectly random.

"If you're last to pick in a group of three, then it's twice as likely that the first picker is buying you a present than the second picker," says Dr Hannah Fry. But she has a solution. Create a set of cards, one for each person. Each card should resemble fig 1. Place the cards face down in a row, shuffle and, keeping them face down, cut them in half. Now shift the cards on top one place to the right (fig 2).

Each person takes a card from the top row and the card directly below it – telling them their number and the number of the person they're buying for (fig 3). Finally, you put a list of numbers on the wall and everyone writes their name next to their number. Such a draw is truly anonymous and perfectly random.

fig 1.

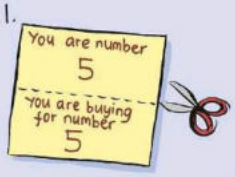


fig 2.

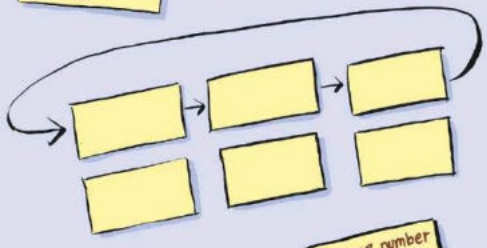
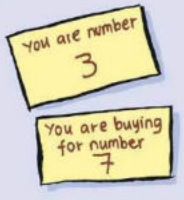
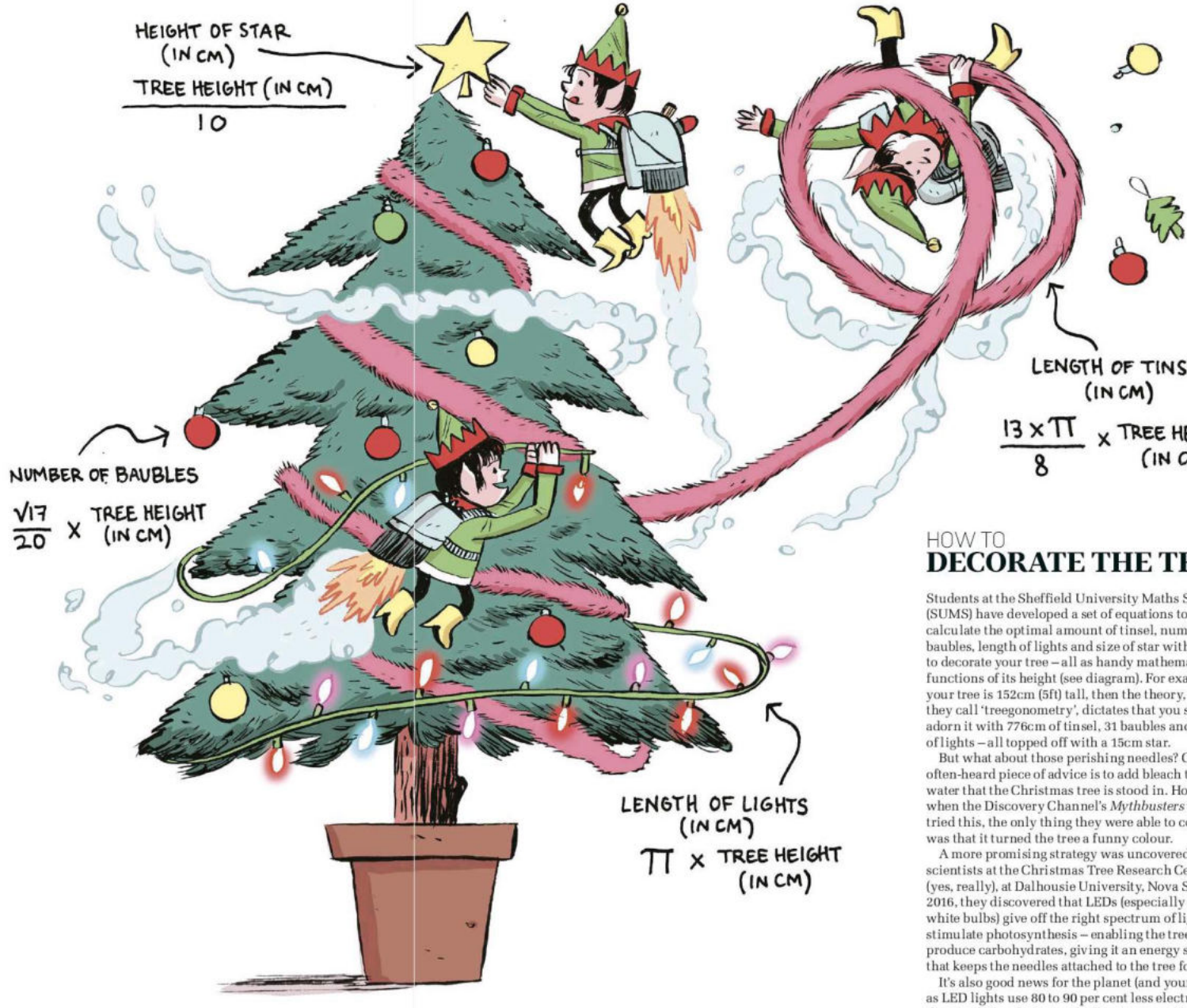


fig 3.





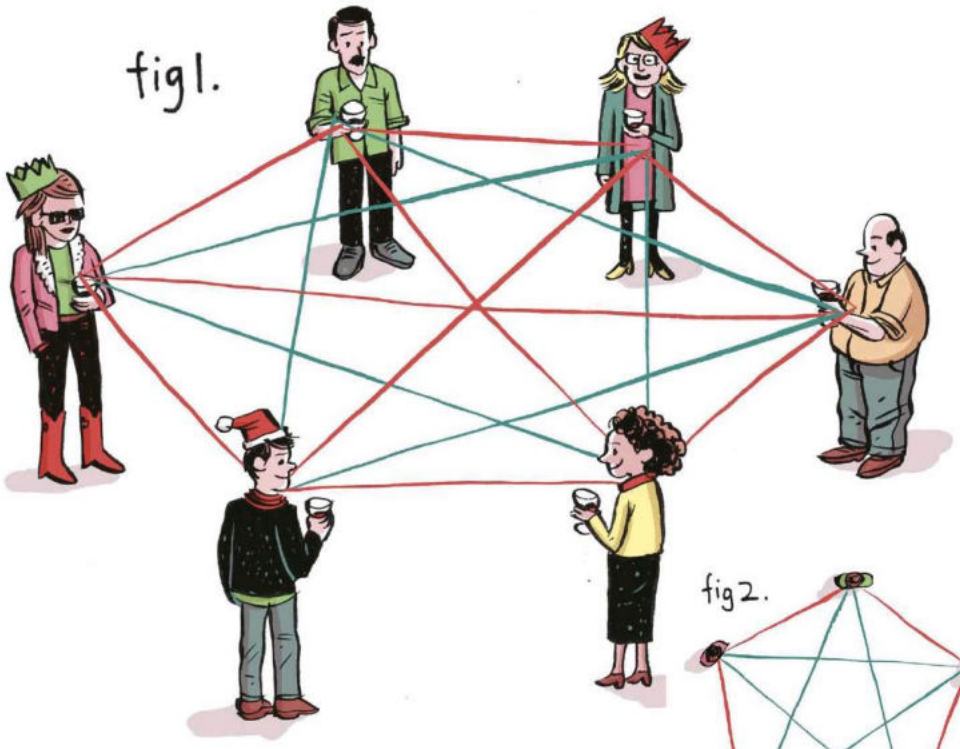
HOW TO
DECORATE THE TREE

Students at the Sheffield University Maths Society (SUMS) have developed a set of equations to calculate the optimal amount of tinsel, number of baubles, length of lights and size of star with which to decorate your tree – all as handy mathematical functions of its height (see diagram). For example, if your tree is 152cm (5ft) tall, then the theory, which they call 'treegonometry', dictates that you should adorn it with 776cm of tinsel, 31 baubles and 478cm of lights – all topped off with a 15cm star.

But what about those perishing needles? One often-heard piece of advice is to add bleach to the water that the Christmas tree is stood in. However, when the Discovery Channel's *Mythbusters* team tried this, the only thing they were able to confirm was that it turned the tree a funny colour.

A more promising strategy was uncovered by scientists at the Christmas Tree Research Centre (yes, really), at Dalhousie University, Nova Scotia. In 2016, they discovered that LEDs (especially red and white bulbs) give off the right spectrum of light to stimulate photosynthesis – enabling the tree to produce carbohydrates, giving it an energy source that keeps the needles attached to the tree for longer.

It's also good news for the planet (and your pocket) as LED lights use 80 to 90 per cent less electricity than traditional filament bulbs. For more tips on keeping your tree looking spruce (sorry), see p98.



HOW TO
THROW A XMAS PARTY

So you're having people over at Christmas – but how many to invite? To encourage conversation, you want either three or more guests who are mutual strangers, or three or more who are already acquainted. So what's the minimum number of people you need at the party to ensure this?

In 1928, British mathematician Frank Plumpton Ramsey found the answer with his theory on the connectedness of points on a graph. The 'Ramsey numbers' R(m, n) give the number of people to invite such that at least either m of them know each other, or n of them don't. It turns out that R(3, 3) = 6.

To see why, draw six dots on a sheet of paper, each representing a guest. Now draw lines from each guest to every other guest – red if they know each other, blue if they don't. With six guests (fig 1) you'll find it's impossible to connect them all without creating either a red triangle (ie, three people who know each other) or a blue triangle (three people who are strangers). But this isn't the case with just five dots (fig 2) – so six is the minimum number of people to invite.

Some more Ramsey numbers are shown in the table to the right. Notice that these are also symmetric, so R(m, n) = R(n, m).

m	n	R(m,n)
3	3	6
3	4	9
3	5	14
3	6	18
3	7	23
3	8	28
3	9	36
4	4	18
4	5	25

HOW TO
PACE YOUR DRINKING

Ever overdone it with the sherry on Christmas Eve?

In 1932, Swedish chemist Erik Widmark studied how ethanol (the pure alcohol in your plonk) interacts with the human body, and used his findings to devise an equation for a drinker's blood alcohol concentration (BAC). The BAC can be used to infer state of drunkenness, allowing the mathematical imbiber to plan their consumption accordingly.

The basic formula is shown in fig 1. G is the amount of alcohol consumed (in grams), t is the time since drinking began (in hours), W is the drinker's weight (in kilograms), r is the gender constant (0.68 for men, 0.55 for women), and ◘ is the rate that alcohol is eliminated from the body (in %BAC per hour, ranging from 0.01 for people with low tolerance up to 0.035 for seasoned boozers). Grams of alcohol is given by the 'alcohol by volume' (ABV) percentage of your beverage times the amount consumed in millilitres times the density of ethanol (= 0.789g/ml).

You can then look up the resulting BAC on the effects table to the right. For example, a man drinks five pints (2840ml) of 5% beer – that's 112g of ethanol (2840 x 0.05 x 0.789). If he weighs 90kg and has a moderate alcohol tolerance (◘ = 0.02) then his BAC after two hours is 0.143. Which is enough co cause a significant risk of missing Christmas dinner.

fig1.

$$\%\,BAC = \frac{G}{10 \times W \times r} - \beta \times t$$

$$G = ABV\,\% \times Volume \times 0.789$$

BAC	Effects
0.02-0.039	Minor euphoria, relaxation, no visible effects
0.04-0.069	Euphoria, reduced inhibitions, slight impairment of higher brain functions
0.07-0.099	Balance, speech, vision and reaction time all mirorly impaired; memory, concentration and reasoning all impaired.
0.1-0.125	slurred speech, lack of balance, reaction times significantly impaired
0.126-0.159	Vision blurred, difficulty walking straight, possibility of anxiety, severe impairment of senses and higher reasoning
0.16-0.199	Complete lack of coordination, anxiety, possibility of nausea
0.2-0.249	Confusion, disorientation, needs help to stand, vomiting likely, possibility of passing out.
0.25-0.299	All body functions severly impaired
0.3-0.349	Complete stupor, loss of awareness, passing out likely
0.35-0.399	Risk of coma and death
0.4-	Coma and significamt risk of death

Dr Paul Parsons is a science writer and an analyst with the bookmaker BetVictor. He tweets from **@NasaProPlus**.

PHOTO: PRESS ASSOCIATION

CAN MATHS DEFEAT TERRORISM?

Mathematicians are finding patterns in apparently random acts of terrorism that may provide clues as to how to how we can thwart such attacks *before* they take place

WORDS: **ANDY RIDGWAY**

Barcelona, 17 August: 13 dead. London, 19 June: one dead. London, 3 June: eight dead. Manchester, 22 May: 22 dead. Paris, 20 April: one dead. Stockholm, 7 April: four dead. London, 22 March: five dead. So goes the list of terror attacks and the number of lives claimed across the UK and Europe in 2017. Each attack was shocking, unpredicted and random. But what if within lists of attacks like this, the cold, hard data of terrorism, there was a hidden pattern – information lurking within the statistics?

It's a question that came to physicist Professor Neil Johnson at the University of Miami while he was visiting Bogota in Colombia in the 1990s. Since the mid-'60s, the country has been in the grip of a conflict between the government and a host of insurgent groups. "I'd turn on the news and three were killed today, then no one, then five, then two, then six," says Johnson. "It's a complicated set of numbers and I thought, let's look at them – it's typical for a physicist to want to do that." His efforts to find a signal in that noisy data proved fruitful.

Later, when he and economist Professor Mike Spagat at Royal Holloway, University of London, analysed a database of 20,000 attacks in Columbia and plotted the number of attacks against the number of people killed in each of them, they found that rather than seeing a classic bell curve – the graph that describes most things in nature, from height to lifespans of individual species – what they saw was a steeply sloped graph that quickly levelled off, with a long 'tail'. It reflected the fact that there had been a large number of attacks with a small number of casualties, and a small handful of attacks with a very high death toll. When they did the same with data that followed the 2003 invasion of Iraq, it showed exactly the same pattern.

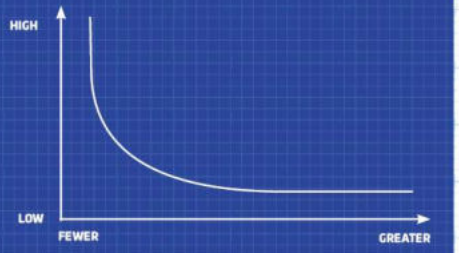
What they'd discovered was a 'power law', a mathematical relationship found in phenomena right across science – everything from how the molecules in materials behave when they're heated, to the frequency of earthquakes and even the masses of stars (see 'What is a power law?', p58).

The power law's discovery in the realm of terrorism has a chilling consequence. But it also raises the question whether these seemingly random acts might actually be predictable in some way.

DEMAND FOR DATA

At the same time as Johnson was uncovering the power law relationship between the number of terror attacks and their scale, computer scientist Asst Prof Aaron Clauset at the University of Colorado at Boulder was doing just the same.

"After a terror attack, it's pretty standard for people to say, 'He was a really decent person'. But it's much more about the groups they were in."



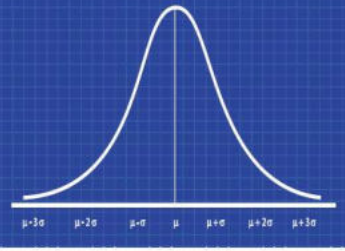
WHAT IS A POWER LAW?

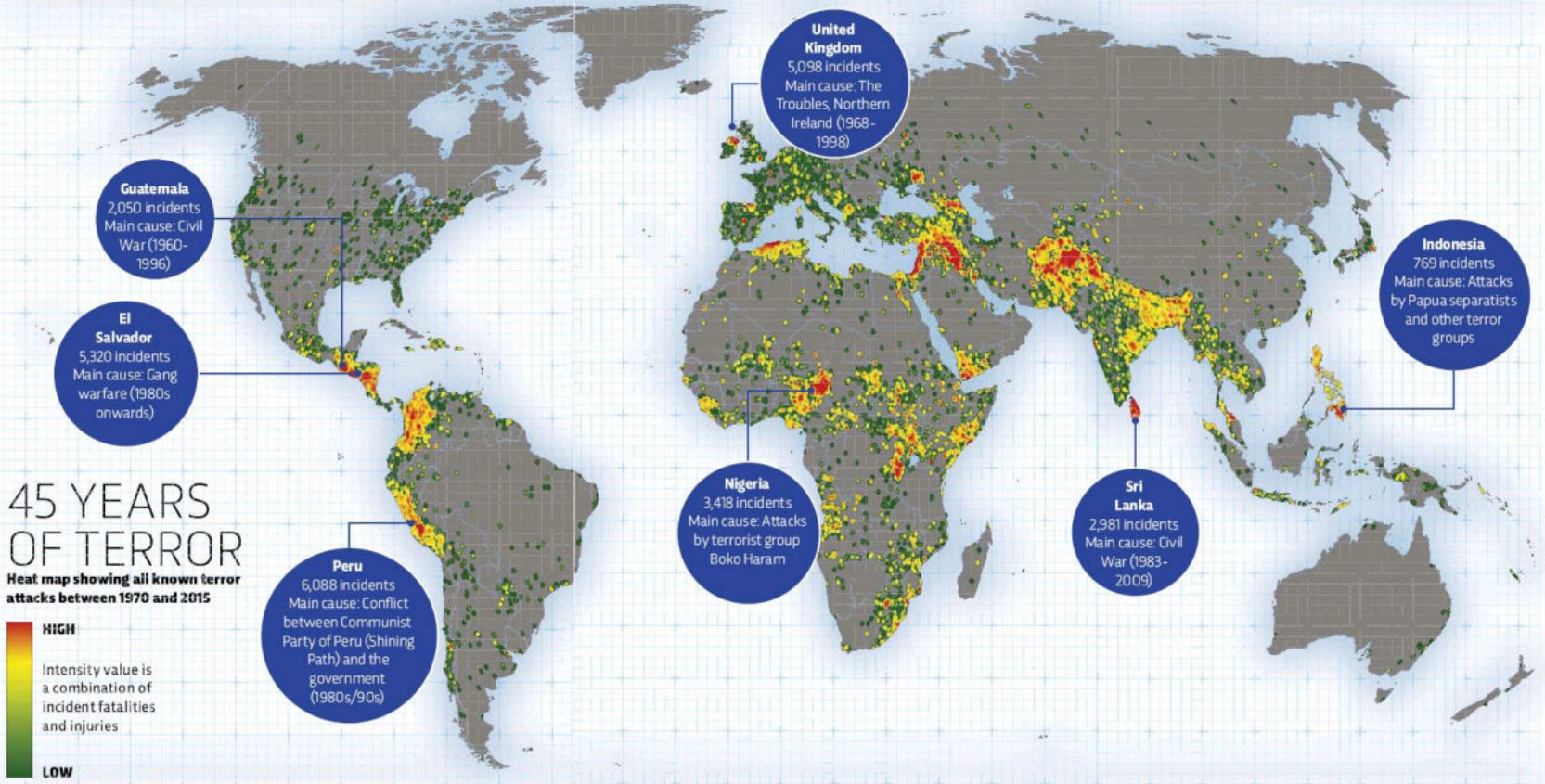
The power law is a way to describe the relationship between two things, and states that a change in one thing results in a proportional change in the other thing. Take a square, for example: if you double the length of its sides, its area is increased four times, or by a *power* of two. Such relationships exist in all kinds of phenomena, from earthquakes to income levels.

Plot these power law relationships on a graph and it shows that the most common things are those at the smallest scale, whether that's the level of income or the size of earthquakes. But there are also a few extreme 'events', like massive earthquakes or huge incomes. That's not true of other things: plot people's height or weight on a graph and you'll get a bell curve, in which most people are towards the middle and extreme 'events' are much less likely.

When it comes to terrorist events, a power law describes the relationship between the number of events and the number of people killed. It tells us that the 9/11 terror attack was not an anomaly – such an event is likely, statistically speaking, to occur again.

Written out, the power law is fairly simple: $Y = k X^{-a}$. Here X and Y are two variables that you're looking at the relationship between, say the number of terrorist incidents and the number of people killed. K is a constant, something that doesn't change over time and 'a' is the law's 'exponent' – the 'power' bit of the equation that shows how much Y changes as X increases or decreases. With terrorist incidents, it was found to have a value of 2.5.





Source: Global Terrorism Database

BELOW: **Map showing all known terrorist attacks worldwide over the past 45 years**

Both of them were harnessing data from the Global Terrorism Database (GTD), a record of terror attacks around the world since 1970.

"One of the key problems with scientific approaches to trying to understand terrorism is getting the data," says Clauset. "For the most part, terrorists don't record their activities in nice structured formats. If you can't measure it, you can't do science with it."

The task of recording data on terror incidents has been taken up by staff and students at the University of Maryland, home of the National Consortium for the Study of Terrorism and Responses to Terrorism (START). Here, computers use natural language processing to sift through 50 million newspaper articles per month and find reports of attacks. It's then down to a team of 10 analysts, helped by student volunteers, to read through the 16,000 articles the computers pick out per month and sift out any mistakenly identified as being terror-related. The articles weeded out are fed back to the computers so their artificial intelligence system can continually improve. The analysts then record 120 different variables about each attack such as the weapons used, the types of target and the number of people killed. The data they generate is released in chunks annually and is freely available on the GTD website.

The data isn't perfect, because it relies on press reports. "There is inherently a bias," says Clauset. "If an event kills someone, it's much more likely to end up in the news media. If it's obviously terrorism, it's much more likely to be written about as terrorism. Small scale, non-lethal terrorism not claimed by any group is under-represented." But it's the best data there is, and when it's analysed it shows the power law in terror attacks, just like data from conflicts around the world.

The discovery of the power law relationship between the number of attacks and the number of people killed allows forecasts to be made. "It allows us to extrapolate in a mathematically principled manner, to make statements about events that are incredibly rare."

It's this kind of extrapolation that led to Clauset's forecast that the chance of another terrorist attack on the scale of 9/11, that killed 2,996 people, is 30 per cent over the next 10 years. The maths can build expectations about the frequency of

"One of the key problems with scientific approaches to trying to understand terrorism is getting the data"

ABOVE: Inside a Special Operations Room run by London's Metropolitan Police

large-scale terror events, says Clauset. "But it doesn't allow us to predict when, why or how the next event will happen."

Some researchers, though, are using maths to try and predict *who* will be behind the next attack.

EXPLANATION REQUIRED

Before getting to the point of making predictions, there are other big questions to answer, such as why this 2.5 'power law of war' exists in the first place – especially given that the conflicts it describes are so different. "Some conflicts are Marxist, some fascist; it's not the terrain, because some are in the jungle, some in the desert, so it must be something else," says Johnson.

The first clue comes from the conflicts where the 2.5 power law *doesn't* hold, such as World War II or the Spanish or American civil wars, where the conflicts were between two or more fairly evenly matched sides. In contrast, the conflicts where it does hold are asymmetric, involving two or more sides with very different resources at their disposal in terms of weapons and people. "We thought about what we see when we heard about attacks in places like Iraq or Colombia. They sound like a loose arrangements, where groups come together to do something and then vaporise," says Johnson.

When the number of these insurgent groups is compared the sizes of the groups, something familiar pops out – the 2.5 power law. In other words, the distribution of the sizes of the groups is almost identical to the distribution in the scale of attacks, with lots of small ones and a handful of very large ones. After all, it's logical that the handful of large groups it predicts will be able to carry out far more destructive attacks than the vast number of small groups or 'clusters' of fighters.

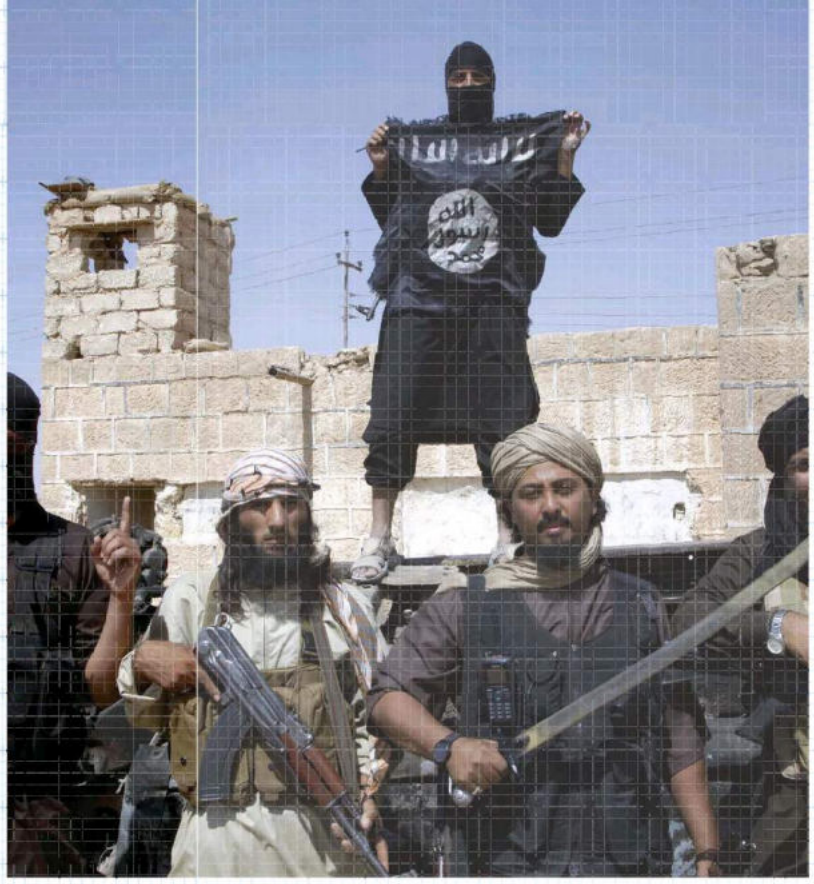
"By cluster, we don't necessarily mean that the members have to walk round in a bunch, like kids in a playground," says Johnson, "but that they are coordinated in some way, such as by some means of modern communication. So it can apply to a cluster of people in the desert during the Iraq era, but it also applies to more tech-savvy situations of a group of terrorists located in different places."

This evidence for the number of groups and their size doesn't come from groups identified on the ground. "It's impossible to know the size of a cluster carrying out attacks," says Johnson. But what is easier to get data on are the online groups of individuals who support a cause or ideology. In fact, the data is freely available, as most groups are visible online to encourage new recruits.

Johnson and his colleagues studied pro-ISIS groups that share operational information, such as advice on financing terror attacks or how to avoid drones. Where Facebook shuts extremist groups down quickly, pro-ISIS groups seem to be more prevalent on other online platforms, which perhaps have fewer resources to check what's being posted. In a study of open-access information on the platform VKontakte, based in Russia, Johnson found 196 pro-ISIS groups with over 100,000 followers. Although groups were shut down by moderators within weeks of being created, the members would just go on to form a new aggregate or join another existing one. It's these groups that followed the power law in their scale. And this fluid online world of ISIS support, where groups coalesce, disappear and re-form, suggests a means to thwart these groups – split them up before they have time to form larger, more deadly groups.

IDENTIFYING POTENTIAL TERRORISTS

Having characterised this ecosystem of online groups, Johnson and his fellow researchers have now shifted their attention to how individuals move through them, finding groups that match



ABOVE: ISIS fighters on the border between Syria and Iraq in 2014

PHOTOS: PRESS ASSOCIATION, ALAMY

"After a terror attack, it's pretty standard for people to say, 'He was a really decent person'. But it's much more about the groups they were in."

their interests and shifting to new ones when groups are broken up. They found that despite there being many possible ways to move around, certain patterns emerge, and that individuals can be described in just a handful of ways. Some people, for example, will at some point express such extreme views that their account will be banned by moderators, while others will delete their own accounts, perhaps through fear of being linked to an extremist group.

To better understand how individuals move though these online ISIS-supporting groups, Johnson turned to a 'stochastic walk model', which predicts how people move through an imaginary 3D space. In this case, that space is the online ecosystem of pro-ISIS groups, and the destinations are being getting banned, self-deleting or something else. Stochastic processes are those that randomly change over time and are found everywhere, from the fluctuations of electrical currents to the movements of gas molecules.

Not only is this allowing Johnson to develop timelines of movements of individuals though this online world, it's also allowing him to study what determines an individual's ultimate destination (ie, banned or otherwise). "Part of it is the groups they pass through," he says. "This is what we're working on now. Is it worse if I go through two extreme groups without having a more spiritual group in-between, or is it worse if I go through a couple of spiritual groups and then on to an extreme one?"

It's the people who end up being banned, the ones posting the most extreme content, who are of most interest to the authorities, says Johnson, because they are the most likely to carry out an attack. Fortunately, those who get banned most quickly tend to follow similar patterns in their movements, making them more predictable. And how this can be used doesn't end with ISIS. Other forms of extremism exist online, such as far left and far right ideologies, and the findings about the movements of pro-ISIS individuals are likely to be more widely applicable.

The focus on groups and their influence is the right way to think about this, says psychologist Professor Alex Hasslam at The University of Queensland in Australia. An expert on how groups influence individuals, he was involved in the BBC Prison Study in 2002 that saw volunteers spending time in a mock prison to see how they behaved.

"After a terror attack, it's pretty standard for people to say, 'He was a really decent person, I'm shocked at this'," says Hasslam. "But it's much more about understanding the groups they were in."

Being able to predict who is more likely to engage in terrorism from their trajectory through online groups leads to an ethical question: what to do when someone who seems to pose a threat is identified? Johnson sees it simply as "an additional piece of information that the legal system can decide how to use," but Clauset urges caution.

"The idea of looking at precursor signals or trajectories isn't unreasonable," he says, "but I think the standards for believing these things are correct must be very high, because we are talking about people's lives here."

Andy Ridgway is a freelance writer and editor who specialises in science, health and social issues.

MEET THE MAMMOTH HUNTERS

WORDS: DR HELEN PILCHER

Melting permafrost and a market for mammoth tusks is fuelling a new, dangerous trade in deepest Siberia

In the Siberian summer, the Sun never sets. Along the banks of the Kolyma River in the region's northeast, straggly larch and tall spruce trees preside over a patchwork of lichen and moss. It's one of the world's last great wildernesses, but its beauty is being eroded – literally – by an underground business that is booming. Every year, clandestine crews of men head to the region to look for hidden treasure: the tusks of woolly mammoths that lie frozen in the permafrost. It's dirty, backbreaking work. They sleep in makeshift tents, live off canned beef, noodles and vodka, and operate illegally, ripping the mammoth remains from the earth with a level of brute force never seen before. They sell the tusks at great profit, creating a new 'gold rush' – not in precious metals, but in body parts. And amidst it all, concerns are mounting that the practice could have a devastating effect on the mammoth's modern-day cousin, the African elephant.

PHOTOGRAPH BY CHAPPLE ON ASSIGNMENT FOR RADIO FREE SERIOUS

The mammoth graveyard

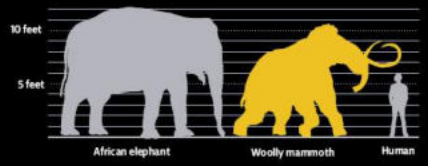
Fifty thousand years ago, Siberia looked very different from how it does today. Instead of forest and scraggy tundra, the region was blanketed in lush grasslands and fertile soils, and herds of woolly mammoths roamed the open plains. Then little by little, towards the end of the last Ice Age, their numbers started to diminish. No one really understands why. Some blame human hunting, some climate change, others a bit of both. What we do know is that they disappeared from Siberia 10,000 years ago, then from their final hiding place – a northerly island called Wrangel – just 3,700 years ago. Now Siberia is a massive mammoth graveyard, and it's estimated that the remains of

Mammoth facts

Latin name: *Mammuthus primigenius*
Lifespan: 60 years
Closest living relative: African elephant (*Loxodonta africana*)
Extinction: Climate change and human hunting both played a part in the mammoth's demise
Adult size: Adult males stood up to 3.4m tall and weighed up to seven tonnes (that's about the same as three London black cabs)

Range: Africa, Europe, Asia and North America

Lived: From the Pliocene epoch (5 million years ago) until the end of the Pleistocene (10,000 years ago). A tiny, isolated population survived on Wrangel Island in the Arctic Ocean until 1650 BC.



Sold down the river

As our world warms, the permafrost is melting and the remains of these fallen giants are starting to surface. Occasionally, tusks can be spotted poking out of landlocked tundra, but more often than not, they are found in places where the permafrost erodes naturally, like river banks and coastlines. In settlements that turned into ghost towns after the fall of communism, mammoth tusks have offered a lifeline to the region's indigenous people, who are still legally allowed to collect them. A single tusk can change a man's life. In rural Siberia, where the average monthly salary is around $500 (£380 approx), a 65kg tusk can net its finder upwards of $30,000 (£22,700 approx). As a result, tales of 'get rich quick schemes' have spread, luring a new breed of hunter that arrives by boat.

The clandestine crew

It's hard to know exactly who these new tusk hunters are, or how many of them are operating. "The mammoth tusk trade is a very difficult theme," says Semyon Grigoriev, head of the Mammoth Museum at the North-Eastern Federal University in Yakutsk, Siberia. "Most tusk hunters work illegally, so they don't like public attention."

While some permits are available for recognised companies, the majority of tuskers work without permits for unspecified middlemen, who then sell on the tusks to the Far East. Grigoriev says. Whereas locals prod the tusks from the tundra with spades and spears, these new hunters work in gangs, raiding the riverbanks with industrial-style equipment that wouldn't look out of place in a fire station.

PHOTOS: AMOS CHAPPLE ON ASSIGNMENT FOR RADIO FREE EUROPE

Blast off!

They blast the riverbanks and crumbling permafrost cliffs with jets of water, drawn from the nearby river or sea. Power comes from makeshift petrol-powered water pumps, converted from the engines of snow mobiles and other vehicles. The pressurised cannons reduce the icy permafrost to a slurry of smelly, pebbly sludge, which then oozes back into the waterways. Any body parts that are liberated come tumbling to the ground. Because the permafrost has remained frozen since the end of the last Ice Age, some 11,700 years ago, the remnants are perfectly preserved. Intact tusks are kept, but everything else – bones, teeth and tusk fragments – are discarded and left to the elements. In the years that follow, these will either wash or weather away.

Unnecessary damage

Sometimes the men gouge out entire hillsides, boring tunnels that stretch for 60m or more into the earth. "This is a new phenomenon in Russia," says palaeogeneticist Prof Love Dalén from the Swedish Museum of Natural History in Stockholm, who routinely visits Siberia to source remains for his scientific studies. "Obviously it's not good, because they're destroying the permafrost and it leaves big scars." To maximise their rewards, the tuskers try to find areas where the density of bones is particularly high. This is a source of frustration to Dalén, because these mass graveyards are of special scientific value. "They're either a human kill site, or some sort of natural trap where the mammoths have died," he says.

PHOTOS: AMOS CHAPPLE ON ASSIGNMENT FOR RADIO FREE EUROPE

Science's loss

The result is that tusks that could be used for scientific research are lost to the ivory trade. In life, a mammoth's tusks were up to 4m in length, and were used to help forage for grass beneath the snow. Today, they provide a valuable record of the animals' lives. As well as containing DNA which can be used for genetic studies, the tusks contain a series of growth rings, much like a tree trunk. From this, researchers can deduce the animal's age, but also snippets of its life story. The tusks of adult females, for example, grew more slowly during pregnancy, so from tusks it's possible to tell the number of offspring that were produced.

Buried treasure

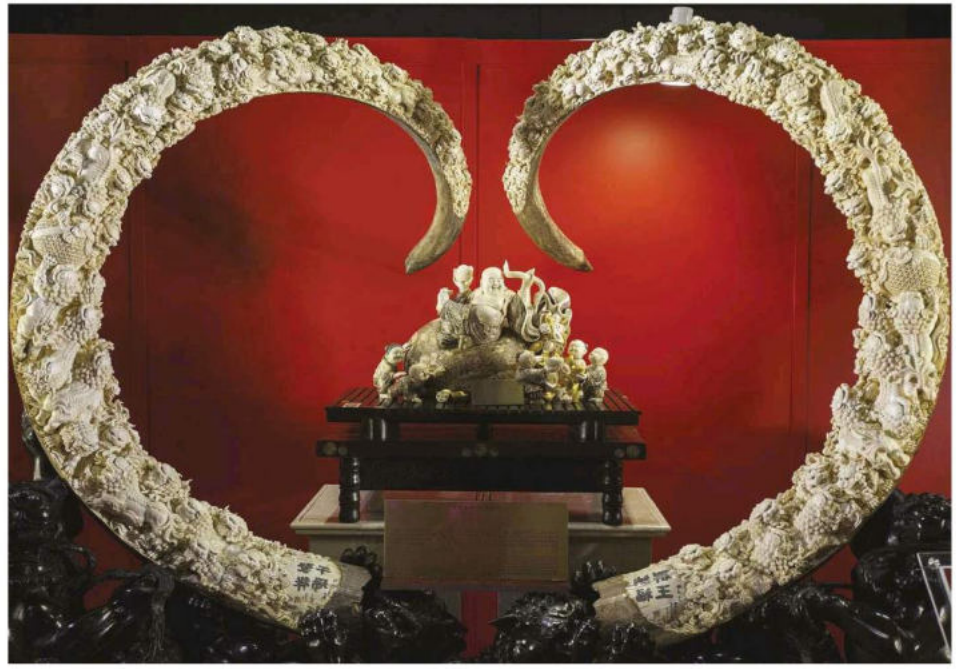
So the tuskers bore deeper and deeper, in search of more ivory. Sometimes they create huge underground caves. In 2012, Dalén visited a site with around 30 tunnels. It had been excavated a few years previously when the hunters took the tusks of a baby mammoth they had found. Dalén and the team wanted to recover the body, but in the repeated thaws of successive summers, the tunnels had become unstable. The one they were in collapsed before they could find the mammoth, moments after the team crawled out of it. "We were five minutes away from losing maybe 12 people," he says.

Sleeping on the job

No one knows how many tuskers have been injured or killed. Because the operation is illegal, no records are kept. Although the inside of a fresh tunnel is rock hard, there's a risk inside of low oxygen levels, and outside of landslides around the entrance to the caverns. The most dangerous element, however, isn't the tunnels but the waterways. The rocky rivers are murky from the dislodged sediment, and full of driftwood and felled logs. These men crashed their boat at speed near a spot where two prospectors drowned last year. When a 3am rescue mission found them (it's still daylight at that time), they were passed out in a boat full of waterlogged equipment.

It's not just tusks

The ends, however, seemingly justify the means. As well as mammoth tusks, the horns of another Ice Age giant, the woolly rhino, are also prized. A 2.4kg rhino horn will earn its finder around $14,000 (£10,600 approx) when it's sold to an agent who then exports it to southeast Asia. In Vietnam, the horns are ground into powder and used in traditional medicine, in the erroneous belief they have the power to cure everything from gout to cancer, snakebites and demonic possession. Mammoth tusks, however, meet a different fate.



PHOTOS: AMOS CHAPPLE ON ASSIGNMENT FOR RADIO FREE EUROPE, EUROPEAN PRESSPHOTO AGENCY/SHUTTERSTOCK X2

Ethical ivory?

Around 90 per cent of Siberian mammoth tusks – more than 60 tonnes a year – end up in China or Hong Kong, where they are carved into elaborate ornaments. The ultimate status symbol, a carved tusk like this one will cost its owner many hundreds of thousands of dollars. Touted as an 'ethical' source of ivory, some argue that mammoth tusks will ease the demand for elephant ivory, but others counter that the existence of ivory in any form only serves to stimulate the market.

It's a debate that rumbles on, while today, there are just 400,000 African elephants left in the wild. Every year, around 40,000 are killed for their tusks, so the question remains: is it really worth endangering the lives of elephants and tusk hunters for another haul of mammoth ivory, or should we let these sleeping giants lie?

Helen Pilcher ponders the possibilities of de-extincting the woolly mammoth in her book, *Bring Back The King: The New Science Of De-extinction*. She tweets from **@helenpilcher1**

CAN WE TRUST ARTIFICIAL INTELLIGENCE?

Deep learning is used in everything from speech recognition software to the assessment of mortgage applications. The only trouble is, **we don't really know how it works…**

ILLUSTRATION: SAM FREEMAN

"IT'S THANKS TO DEEP LEARNING THAT WE HAVE SIRI, CORTANA AND ALEXA"

Deep learning does it all: face recognition, speech recognition, language translation, automated game-playing. It's an approach that has transformed the field of artificial intelligence (AI) and is without doubt the AI flavour of the decade. It works amazingly well.

But increasingly, questions are being asked about transparency. Exactly how does deep learning work? Can we trust it to work for safety critical applications such as self-driving cars? We generally like computer algorithms to be as transparent and revealing as possible – and this is not the case when it comes to deep learning.

In essence, deep learning is really a clever rebranding of an earlier computer learning method called artificial neural networks (ANNs). Dating back to the beginning of computers, ANNs are computer programs that simulate networks of neurons like those in our own brains. They're hugely simplified and don't really work in quite the same way that real neurons work, but nevertheless, they enable computers to learn (see 'How a neural network works', opposite).

HIDDEN DEPTHS

Research on neural networks started in the 1950s and the ideas were refined over many decades, but it became clear that neural networks were not as good as some other approaches in machine learning (the branch of AI dedicated to helping computers learn from data in order to make classifications and predictions). As a result, research in the area began to wane by the early 1990s, and learning methods that relied on clever statistics started to dominate.

This all changed about 20 years ago. British pioneer Geoff Hinton (University of Toronto and head of Google's Brain Team Toronto), and Jürgen Schmidhuber (IDSIA Dalle Molle Institute for AI, Switzerland) introduced new, more efficient ways to train neural networks containing far more layers. Suddenly networks could have hundreds of 'hidden' layers – rows of neurons that sit between the input neurons, which are connected directly to the various sensors, and the output neurons, which provide the results. When combined with new ways of connecting the neurons to each other, the result was massively more powerful. The breakthroughs also coincided with the age of big data, cloud computing and fast processors (including graphics cards originally designed to make computer games zippy). By 2006 it was possible to create gigantic 'deep' networks, train them with vast quantities of data, and use huge numbers of fast computers all working in sync.

ABOVE: **Jurgen Schmidhuber at 2016's Digital Life Design conference in Munich**

PHOTOS: GETTY, ALAMY

It was the start of the newest revolution in AI. Deep learning works. Although still based on a very simplified model of how the brain functions, it relies on unprecedented networks of thousands or millions of neurons simulated in software. Given enough data (and today we have vast amounts) and enough computers (and today we have plenty) to enable the networks to adapt and learn in response to the data, the result is like a little software brain.

If it's been trained to recognise faces, then this little face-recognising brain can be duplicated a few million times and placed into every camera, so that when you take a photo it finds faces and ensures they are in focus. If it's been trained to recognise speech, then the little speech-recognising brain can be placed into your phone so that it can understand the words you have spoken. If the brain has a lot of neurons, it can even run in the cloud, and when you speak, your words are sent to these remote computers which do the deep thinking, and return the results back to your device in the blink of an eye.

In the last decade, deep learning has resulted in some startling advances in the field of machine learning. It's thanks to deep learning that we have Siri, Cortana and Alexa; it's because of deep learning that we have automated machine translation, face recognition, and automated captioning of images. But not everything is rosy. While these massive neural networks show some truly remarkable capabilities that spookily resemble the capabilities of biological brains, they also share another of a real brain's properties: a lack of transparency.

INTO THE UNKNOWN

In a biological brain, we still have surprisingly little idea exactly where information is stored, or exactly how decisions are made. We know it's all something to do with those neurons, but we can't point to one group of neurons and say, "That's where you remember the taste of chocolate," or point to another group and say, "That's where your decision to buy a new toothbrush was made".

In exactly the same way, we have no idea where information or decisions are stored inside these giant artificial neural networks. They are black boxes to us. We cannot see inside them. In science and engineering, this is not a good thing. When we have safety critical technology, we want to be able to prove that the technology is always going to work. For example, we already have automated trains, and we trust them because the software that controls them is formally proven to be reliable, using mathematics.

Today, many automobile manufacturers are working on autonomous vehicles, and most if not all of them are using deep learning as part of the systems to interpret sensor data and recognise hazards on the road. Tesla, for instance, is one of the first companies to sell vehicles with an autonomous driving mode – and it's one of the first to encounter problems. Last year, one Tesla driver placed too much trust in his car, which drove into the back of a stalled van. Tesla does warn drivers to stay alert while using the system, but Andrew Ng – founder of Google's Brain Project, and pioneer of the use of deep learning to learn without supervision – commented on the crash, tweeting, "It's irresponsible to ship a driving system that works 1,000 times and lulls false sense of safety, then… BAM!".

Other recent work by researchers at the Icahn School of Medicine at Mount Sinai, New York has used deep learning to analyse patient records. In 2016 their deep network looked at more than 75,000 patient records and 78 diseases and was able to predict severe diabetes, schizophrenia, and various cancers with high accuracy. This is valuable work that could save lives. But how does a doctor tell her patient that he's likely to develop schizophrenia because a deep network says so? Can a doctor trust a prediction enough to start preventative care, when no explanation is given?

HOW A NEURAL NETWORK WORKS

A typical neural network consists of a number of artificial neurons arranged into a series of interconnected layers. When a neural network is tasked with learning something, input neurons receive the data from the outside world that it's attempting to make sense of.

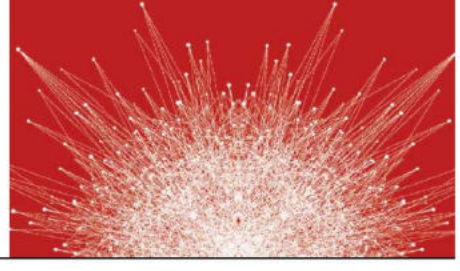
For example, if I wanted my neural network to learn how to read handwriting, I might have a lot of input neurons 'looking' at the pixels in the images of the handwritten letters. This raw data is then converted into a convenient form and passed on to one or more 'hidden' layers – this is where the actual processing of the data takes place.

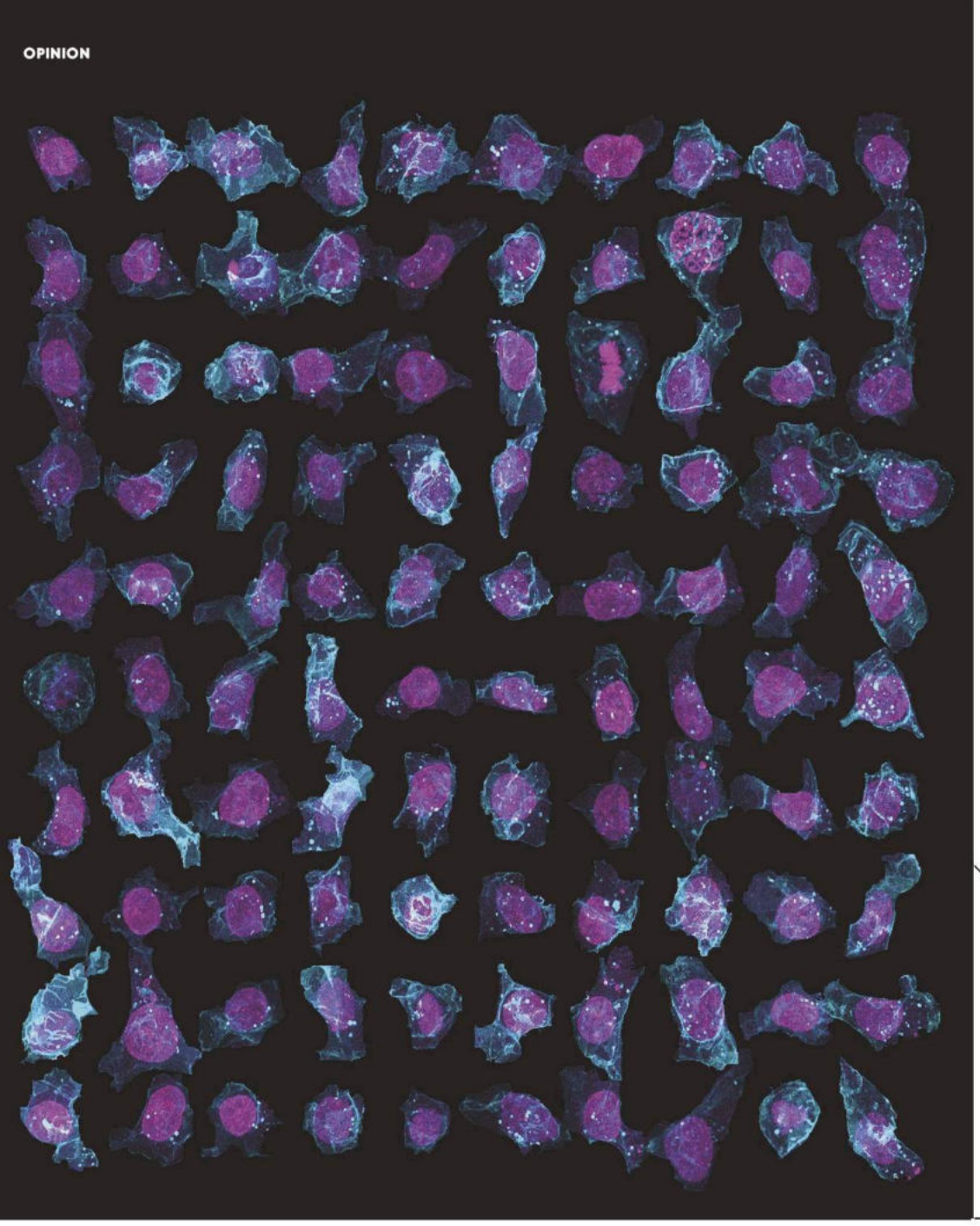
Hidden layers are so-called because their outputs are connected to the input of another layer, and so are not visible as a network output. In the handwriting example, these hidden layers would determine the form of the letters being read.

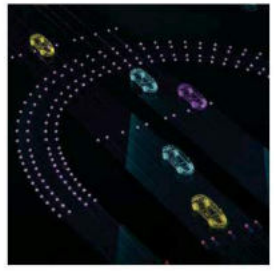
Finally, once the data is processed, it is passed on to an output layer that returns the network's conclusions. For handwriting recognition we could have 26 output neurons – one for each letter of the alphabet.

Large amounts of training data are given as input, causing some of the neurons to be activated and others not. The connections between one neuron and another are represented by a number, or 'weight' – the higher the weight, the more influence one neuron has on another. This is similar to the activity of neurons in your brain when you look at something.

The weights and biases of the neurons in the network are then repeatedly adjusted until the output neurons give the correct answer. This is like a teacher repeatedly telling a student what each image represents, and making sure the student repeats the right answer each time.







ABOVE: **The startling images produced by Google's DeepMind have helped bring machine learning into the public consciousness**

RIGHT: **Deep learning is used in obstacle detection systems for self-driving cars**

OPPOSITE: **The Allen Cell Project is building a deep learning network that can identify the component parts of cells from 3D images**

PHOTOS: ALLEN INSTITUTE FOR CELL SCIENCE, GETTY

A LEGAL CONUNDRUM

The European Union is so concerned about these new technologies that it has already adopted new General Data Protection Regulations, which refer to our rights with respect to machine learning. Due to become law in all EU member states in May 2018, Article 22 states that everyone "shall have the right not to be subject to a decision based solely on automated processing," and the right to be given "meaningful information about the logic involved" in any decision made by a computer.

These are sensible precautions, but the fact is that they're incompatible with deep learning. If your mortgage application is refused because of a deep learning algorithm, you will be legally entitled to an explanation – but it may be impossible to provide it.

Researchers are working on ways to improve this situation. Recent work from Google DeepMind suggests that some explanations could be found by using methods from cognitive psychology – running experiments on the neural networks to try to understand what they're responding to, in the same way that we run experiments on people to understand our own brains. But if you've just had your mortgage refused and the only explanation is "the network sometimes pays a lot of attention to spending on leisure activities, so that might have been the case here," you're not likely to be happy.

Deep networks' lack of transparency isn't shared by other machine learning approaches. It's possible to use other AI techniques for most applications, and have complete, human-readable explanations. Other methods also have the advantage that they may have a better formal (mathematical) underpinning. This means a much clearer understanding of the reliability of the results can be obtained, allowing us to judge how far we should trust the methods. But these other methods aren't deep learning – so they're not seen as 'cool' right now.

There are so many deaths caused by human drivers that making self-driving vehicles safer than us should not be an insurmountable problem. Yet progress towards this goal isn't helped when we can't quantify the risk of using deep learning for specific applications because we don't understand how it works or what it will do – at least not until it's already done it. Our roads, vehicles, buildings and cities are changing. If the workings of the deep learning brains in our autonomous cars are unknown to us, then how can we be confident that they will work when confronted with things they haven't been tested on?

In Europe, the answer is familiar: new regulation for artificial intelligence algorithms. But we need to apply some common sense here. Artificial intelligence is not one technology: it's a thousand different approaches applied to a million different applications. Deep learning is the latest marvel, but like all new technologies it must be tested and certified to work safely for each specific application, before we can trust it with our lives.

Dr Peter Bentley is a British author and computer scientist based at University College London

"CAN A DOCTOR TRUST A PREDICTION WHEN NO EXPLANATION IS PROVIDED?"

HELEN CZERSKI ON... AEROSOLS

"MY FAVOURITE SCARF NOW SMELT LIKE THE START OF A TEENAGE LAD'S NIGHT OUT"

One day last week, I was sitting outside with a glass thermometer, an aerosol spray can and a film crew, regretting having asked the director to acquire the aerosol can. For reasons incomprehensible to me, he'd picked the cheapest, smelliest men's deodorant that he could find, and my favourite scarf now smelt like the start of a teenage lad's night out.

But when I held the bulb of the thermometer directly in front of the escaping plume of spray, the red liquid dropped like a stone. It reached -20°C within five seconds, and the bulb completely frosted up. Even though this demo had been my idea, I hadn't tried it before, and was astonished at the speed of the temperature drop. Physics demos sometimes have a reputation for 'not working' (which is almost always more to do with the experimenter and the setup than physics itself), but this one was jaw-droppingly effective. And so it should be, because that temperature drop is an integral part of how an aerosol works. You can't have one without the other.

We know that aerosols have liquid in them, because we can hear it when the can is shaken. This liquid is a mixture of whatever you're buying (hairspray, air freshener, paint, etc) and a propellant. In my deodorant can, the propellant was a mixture of butane and propane, both of which are gases if you release them to the atmosphere. But they become liquids when you put them under a bit of pressure. Inside a typical aerosol can, the pressure is three or four times higher than the atmosphere, so most of the butane/propane mixture is liquid. Once you empty some of the liquid out of the can by spraying it, a little of the rest of the liquid evaporates to become gas and fills the gap, and so the high pressure stays exactly the same. That's why the spray pressure doesn't change as the can empties.

The cold comes from the second stage. As I held down the button on top of the can (prompting the director to step sideways to avoid being tainted by the scents of his youth), the high pressure inside forced the liquid up a tube towards the nozzle and outwards to meet the big wide world. On reaching the low-pressure air, the propellant instantly evaporated to become a gas, shattering its deodorant sidekick into millions of liquid droplets. So just at the point that the spray left the nozzle, it was a jet of pressurised gas carrying a cargo of tiny liquid scent capsules.

The final act in this drama is that once the gas isn't confined any more, it expands by shoving outwards on the air molecules around it. That has a heavy energy cost, but it has to happen, so the gas molecules themselves get cooler because they've given away energy. The lowest temperature you can reach with a typical aerosol can is around -25°C, way below the normal temperatures of our world. It's only a tiny volume of gas, but it could still damage your skin if you sprayed continuously at a very short distance.

The physics of gases is beautifully elegant, but because most gases are invisible, it's usually hard to see that elegance in the world around us. However, the physical gas laws have nothing to say about the odours that the gases carry with them, and they may be less enticing. I'm off to give my scarf a wash!

Dr Helen Czerski is a physicist and BBC presenter. Her new documentary on temperature will be shown in late 2017.

NEXT ISSUE: THE PHYSICS OF CHAMPAGNE CORKS

ILLUSTRATION: KYLE SMART

Q&A

YOUR QUESTIONS ANSWERED

PHOTO: STRATOLAUNCH SYSTEMS CORP.

Stratolaunch will have the longest wingspan of any aeroplane and, once it's complete, will be used to propel satellites into orbit

Which plane has the biggest wingspan?

TRACEY EVANS, POOLE

The passenger plane with the biggest wingspan is the airbus A380 – a monster double-decker plane that carries 550 people, with a wingspan of 80m. But the overall plane with the biggest wingspan will soon be an aircraft that carries no passengers at all.

Paul Allen, co-founder of Microsoft and one of the world's richest men, has helped create the Stratolaunch. This will be an aircraft with six 747 jet engines and a twin fuselage (the flight crew are all in the right-hand one, and instrumentation is in the left one). The amazing machine will carry rockets high into the atmosphere to make launching satellites cheaper and more reliable. It's still under construction, but its wingspan will be 117m. **PB**

Why do beavers build dams?

SARAH CONNORS, GLASGOW

Dam-building is synonymous with beavers, the ultimate aquatic engineers. Using branches from trees they have felled, these large rodents dam lakes to create moat-like ponds of still water where they construct islands known as 'conical lodges' out of timber, mud and rocks. The body of water surrounding the lodges provides protection from predators – resident beavers enter and exit their sophisticated homes incognito via water-filled tunnels leading from the lodges to the pond. The largest lodge, found in Alberta, Canada, measures over 500m in length – though contrary to a widely circulated myth, it is *not* visible from space! In deep or fast-moving water areas, beavers simply excavate into river banks and set up home there instead. **CC**

How long do six pints of lager stay in my system?

CAROLINE PAGET, EDINBURGH

There is no simple answer. The rate at which your body breaks down alcohol depends on many factors, including your age, sex, weight, metabolism and how much you've eaten. As a general rule of thumb, it takes about one hour for your body to break down one 'unit' (10ml of pure alcohol). A pint of low strength lager contains about two units, while a higher strength one has three. So it could take 18 hours or longer for the alcohol from six pints of strong lager to leave your system. In other words, at least some alcohol will still be in your blood the morning after the night before. **ED**

IN NUMBERS

2.647

Length, in Earth days, of a year on newly discovered exoplanet NGTS-1b, a 'hot Jupiter' lying some 600 light-years from Earth.

41bn

Total carbon emissions from Earth in 2017 – the first rise in emissions for three years.

19.7M

Area in km² of the hole in the Antarctic ozone layer at its winter 2016 peak. That's good news: it's the smallest it's been since 1988.

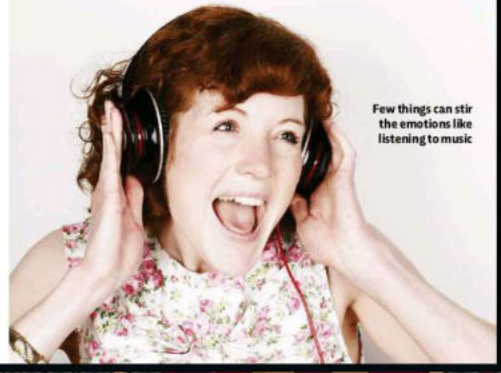
PHOTOS: GETTY X3, SCIENCE PHOTO LIBRARY ILLUSTRATIONS: RAJA LOCKEY

Why does music make us feel good?

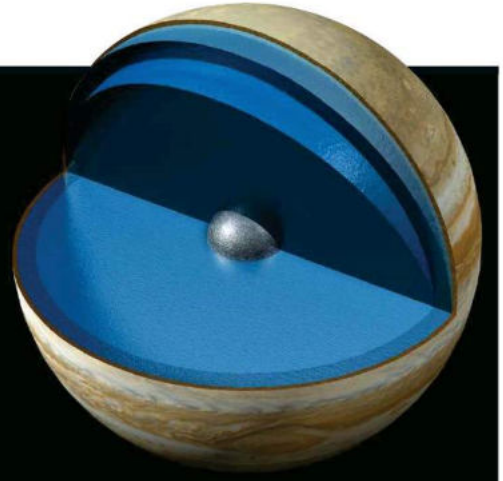
AMMAR EL-BEIK (AGE 12), WINNERSH

At a basic level, it is to do with how our brains have evolved to find it rewarding to look for and find meaningful patterns in sound. Research suggests there is something particularly satisfying about a piece of music that is in some ways familiar, but also contains a few surprises.

Music can also make us feel good by amplifying our current mood (think of the 'pleasure' of wallowing in a sad song when you're feeling down); it can also trigger fond or poignant memories. Then there's the social side: singing along with friends to a new tune from your favourite band fosters a powerful sense of belonging. **CJ**



Few things can stir the emotions like listening to music



What is at the centre of a gas giant like Jupiter?

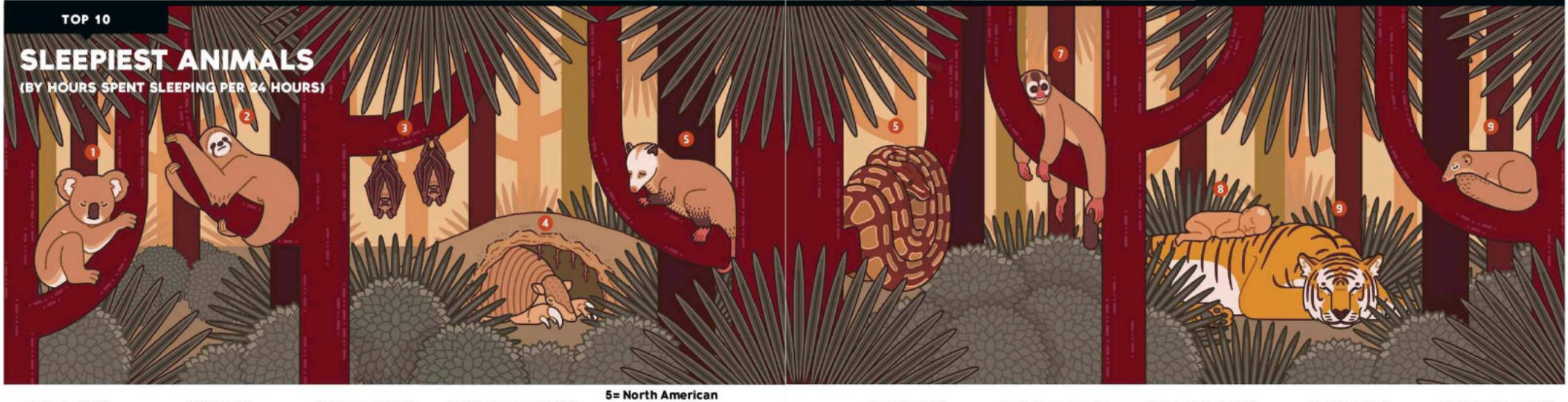
LIAM FARMER, NOTTINGHAM

This is one of the key questions astronomers hope to resolve with data from NASA's Juno mission, currently orbiting Jupiter. Jupiter's atmosphere is made up of around 90 per cent hydrogen and 10 per cent helium, so computer models suggest its core may be made from metallic hydrogen, a bizarre form of the element thought to exist at extreme pressures. RM

TOP 10

SLEEPIEST ANIMALS

(BY HOURS SPENT SLEEPING PER 24 HOURS)

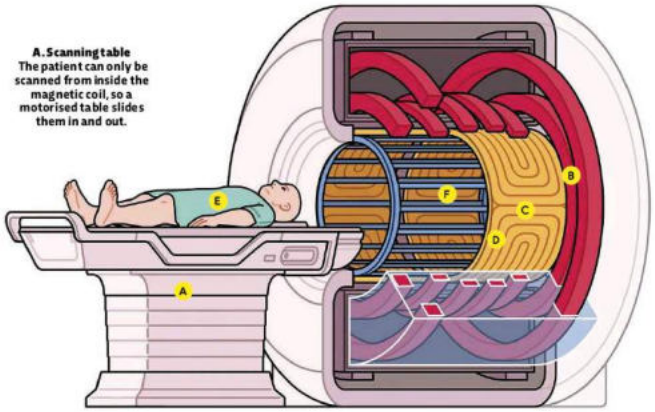


1. Koala 20-22
2. Sloth 20
3. Brown bat 19.9
4. Giant armadillo 18.1
5= North American opossum 18
5= Python 18
7. Owl monkey 17
8. Human infant 16
9= Tiger 15.8
9= Tree shrew 15.8

HOW IT WORKS

THE MRI SCANNER

Magnetic Resonance Imaging (MRI) takes advantage of the fact that the nucleus of a hydrogen atom (a single proton) behaves like a weak compass needle. In the presence of a strong magnetic field, the hydrogen atoms will align themselves, but a radio signal of the correct resonant frequency will cause them to deflect slightly. When the signal is removed, the atoms return to their equilibrium state and emit a radio signal of their own. An MRI scanner can detect these signals and use them to map the distribution of molecules with lots of hydrogen atoms – ie, water and fat. In this way, it can create detailed images of the inside of the body.



A. Scanning table
The patient can only be scanned from inside the magnetic coil, so a motorised table slides them in and out.

B. RF system
An antenna produces a radio signal to 'nudge' the hydrogen nuclei and listen to the answering radio wave they emit.

C. Liquid helium
Liquid helium is pumped through an enclosing jacket to cool the supercon-ducting magnets almost to absolute zero.

D. Main magnet
Superconducting magnetic coils produce a magnetic field of 1.5 teslas – that's about 300 times stronger than a fridge magnet.

E. Patient
The high magnetic fields mean that patients with cochlear implants, pacemakers or embedded shrapnel usually can't be scanned.

F. Gradient system
A second coil distorts the main magnetic field so that the resonant frequency of the protons varies according to position.

Why don't horses have toes?

LESLIE WATERS, HIGH WYCOMBE

Early horses such as *Hyracotherium*, which lived 55 million years ago, did have multiple toes, but they were much smaller animals. For taller animals, excess weight at the end of their legs has a much bigger impact on their speed. A recent study at Harvard found that one broad hoof is almost as strong as multiple smaller toes, but much lighter. Natural selection has gradually discarded the horse's side toes and widened the middle one to increase running speed. **LV**

Why do ants walk in a line?

ANJALI NAIR, INDIA

Ants are highly social insects, thriving in colonies of millions of individuals that work as a team. Good communication skills lie at the heart of their success. They rely heavily on chemical scents, called 'pheromones', to defend territories and exchange complex information – from the location of food sources and nest sites, to the presence of predators. Each ant species has its own chemical vocabulary of up to 20 different pheromones which can be secreted to form specific scent trails. The tips of their antennae translate the chemical 'words', thereby guiding the ants, in a line, to or from the desired destination. **CC**

PHOTOS: GETTY X4 ILLUSTRATIONS RAJA LOCKEY

Ants look highly organised when they're on the march, but they're literally just following their noses

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Does sea air really make you sleep better?

TIM ROWLAND, ST ALBANS

Take a coastal walk and the chances are that you will sleep better, according to a 2015 study by the UK's National Trust. However, there is no evidence that sea air in itself will make you sleep better. At one time, people attributed their sleepiness to certain ions or ozone in sea air. In reality, we probably sleep better after a trip to the seaside because we have had a satisfying amount of exercise and have been lulled by the rhythmic sound of the waves. Those that live their daily lives by the seaside don't tend to report improved sleep. **ED**

What could explain the Star of Bethlehem?

PAUL WILKES, TONBRIDGE

Ancient Chinese records report the appearance of a bright comet in 5BC and also the sudden flare-up of a star in 4BC – both around the time when Christ is now thought to have been born. However, some researchers have claimed these events lack the astrological significance of 'portents' involving the Moon and planets, which would have attracted attention among scholars of the time.

This has led to the emergence of two top contenders for explaining the Star of Bethlehem. The first is a so-called 'occultation' in 6BC, when the Moon appeared to pass in front of Jupiter in the night sky. The second contender is an unusual triple conjunction of Jupiter and Saturn which took place in 7BC, when these two great planets repeatedly appeared close to one another. RM

WHO REALLY DISCOVERED?

BLACK HOLES

LOUISE WEBSTER

PAUL MURDIN

While their enigmatic name was first coined in 1967, the idea of objects whose gravity is so intense not even light can escape them is far older. In 1783, an English cleric and amateur scientist named John Michell showed that Newton's law of gravity suggested such objects could exist. But Michell went further, suggesting that despite being invisible, such objects might reveal themselves if they happened to have a star in orbit about them.

He proved to be amazingly prescient in both respects. During the 1930s, theorists using Einstein's more sophisticated theory of gravity, known as General Relativity, showed that sufficiently massive stars could collapse under their own gravity at the end of their life, and turn into black holes (ironically, Einstein himself never accepted that such strange objects could really exist).

Michell's second claim was confirmed in the early 1970s. British astronomers Louise Webster and Paul Murdin at the Royal Greenwich Observatory and Thomas Bolton, a student at the University of Toronto, independently announced the discovery of a massive but invisible object in orbit around a blue star over 6,000 light-years away. The object, an intense X-ray source codenamed Cygnus X-1, is now regarded as the first black hole to be identified. **RM**

Cygnus X-1

Why did we evolve an imagination?

ZACHARY BEATTIE, KENILWORTH

Imagination underlies our ability to anticipate different futures and to reflect on alternative pasts. Arguably, it's what distinguishes us most profoundly from other animals. It means we can learn from past experiences ("If I'd taken a spear with me, I could have caught the deer") and we can hypothesise about the possible outcomes of future scenarios ("If I trek across the desert without any food or water, I will get hungry and thirsty"). This makes us incredibly adaptive and is the secret to our superlative planning and problem-solving skills. Once imagination evolved, it also unlocked the gifts of storytelling, fantasy and wonder. Q

Is vaping safe?

STACEY HUGHES, BUCKINGHAMSHIRE

The most recent research shows that vaping is much less bad for you than smoking. If you already smoke cigarettes, then switching completely to e-cigarettes will significantly improve your health. But smoking is so bad for you that you could switch to skydiving and still come out ahead! Skydiving every day for 70 years gives a 23 per cent chance of early death, while lifelong smokers have a 50 per cent chance of dying before 70.

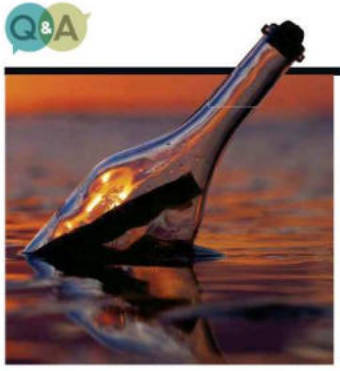
The real question is: can you safely take up recreational vaping, even if you don't already smoke? The evidence for this is much less clear. Nicotine by itself doesn't cause cancer, and vape juice doesn't contain any of the 70 known carcinogens that are present in tobacco. But it does contain other chemicals, such as propylene glycol. When this is heated by the electric element in the e-cigarette, it can create formaldehyde, which is carcinogenic. The different flavour chemicals used in vape juice are all organic compounds, and these can also be altered by the heating element.

Vaping has only been around for a decade, so it is still too soon to be sure of long-term effects. Since e-cigarettes will get you hooked on nicotine just as surely as tobacco does, it doesn't seem wise to take up a whole new addiction. **LV**

PHOTOS: ASTRONOMICAL SOCIETY OF AUSTRALIA, CHANDRA/NASA, MIKE PEEL/WIKIPEDIA, GETTY X2, PETER ESSICK/AURORA PHOTOS ILLUSTRATION: RAJA LOCKEY

WHAT IS THIS?

Wild wetlands
This aerial photo shows part of Sears Point, an area of high land that juts out into the San Pablo Bay in northern California. Over 388 hectares of it are being restored to marshland, as this provides an important habitat for local wildlife and reduces the risk of flooding in nearby towns. The circular 'marsh mounds' seen here prevent waves from forming and carrying away the sediments marsh plants need to grow.



What's the furthest a bottled message has travelled?

DAVID SMITH, LONDON

The longest known single journey was that of a *Doctor Who* postcard in a bottle, thrown into the sea at Tyne and Wear in 2011. This turned up 17 months later in Perth, Western Australia – over 14,500km away. But in 1929, German marine scientists dropped a bottle into the Indian Ocean with instructions for the finder to report where it washed up and then throw it back. This floated for six years and covered 25,600km! **LV**

Are atoms expanding as the Universe expands?

TONY KARGER, NORFOLK

The expansion of the Universe only significantly affects space and time on scales bigger even than entire clusters of galaxies. Below this, the size of objects is dictated by far stronger influences, notably the force of electromagnetism in the case of atoms. Extremely sensitive measurements have found no evidence that the fundamental properties of atoms are anything other than constant. RM

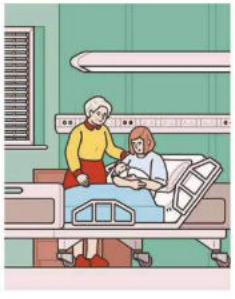
Can a tree grow in space?

SAM TREE, SHOREHAM

Experiments on the ISS have shown that young spruce tree seedlings do grow in microgravity, but they don't look quite the same. The seedlings grow faster, and the pine needles don't point downward so much. DNA analysis shows that several plant genes are more active in space, but we're still waiting to find out the long-term effects on larger plants. **LV**

THE THOUGHT EXPERIMENT

HOW CAN I LIVE TO BE 100?



1. BE BORN LATER

Life expectancy figures normally assume mortality rates will stay the same, but medical and safety improvements are constantly reducing them. A new Danish model that takes this into account found that children born in the developed world today have a 50 per cent chance of reaching 100.

2. BE FEMALE

Women live longer than men, and not just because they tend not to fight wars. Japanese researchers created mice without a father by combining two female genomes. Their lifespan was extended by 30 per cent. Men may be engineered for size and strength at the expense of durability.

3. TAKE VITAMIN D

In the UK, the sun is only bright enough to make vitamin D in our skin between April and September. Vitamin D has been shown to help proteins in your cells keep the correct 3D shape. Misfolded proteins are associated with ageing diseases such as Alzheimer's and Parkinson's.

4. STAY ACTIVE

Daily exercise slows the gradual loss of heart muscle and bone density as we age, and reduces the risk of falls. Once you can no longer walk 400m (0.25 miles) in five minutes, your chance of dying in the next three years rises by 30 per cent.

PHOTOS: GETTY X4, SCIENCE PHOTO LIBRARY ILLUSTRATIONS: RAJA LOCKEY

Why are clowns so scary?

MATT ADAMS, LUTTERWORTH

For many people, there is something disturbing about the clown's make-up that renders their facial expression as an unnatural, fixed grin or smile. This means we can't read their true emotions, putting us on edge. It's probably no coincidence that many of the most infamous horror characters also conceal their faces in some way – think of the *Scream* mask, or Leatherface from *The Texas Chainsaw Massacre*. When the clown also behaves aggressively or menacingly, the contrast with their playful costume and grinning features just adds to the creepiness. But context is everything: children can find friendly, silly circus clowns hilarious. Q

Why do dogs eat grass?

PEARL GOODWIN, LEWES

A 2008 study found that 68 per cent of dogs regularly eat grass but only 22 per cent of them are sick afterwards, so it doesn't seem to be because the dog is ill. Wolves also eat grass, and it may be that this helps to purge their intestines of parasites. Dogs may have inherited this ancestral behaviour even though most pets are regularly wormed. **LV**

QUESTION OF THE MONTH

Does a USB drive get heavier as you store more files on it?

BEN CHELSKI, COLCHESTER

Believe it or not, they get lighter. USB drives use Flash memory, which means the the ones and zeros of your data are stored on transistors. When you save data, a binary zero is set by charging the float gate of the transistor, and a binary one is set by removing the charge. To charge it, we add electrons, and the mass of each electron is 0.000000000000000000000000000091 grams. This means that an empty USB drive (which mostly holds zeros) weighs more than a full USB drive (which has ones and zeros). Add data, reduce the weight. However, you would need to weigh more USB drives than exist on the planet together at once before the difference in weight became easily measurable. PB

USB sticks are actually lighter when full of data

WINNER!

Ben Chelski wins a £50 voucher to spend at online gadget and gift retailer Prezzybox. From Bluetooth speakers and drones to VR headsets and mini submarines, Prezzybox is the perfect place to find your favourite gadget-lover's perfect present! Find out more at **prezzybox.com**

NEXT ISSUE:

How dense is the Universe?

Why is gold yellow?

Can we prevent an asteroid strike?

Email your questions to **questions@sciencefocus.com** or submit online at **sciencefocus.com/qanda**

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

CHRISTMAS 2017 | EDITED BY JAMES LLOYD

01

ROYAL INSTITUTION CHRISTMAS LECTURES
BBC FOUR, 26-28 DECEMBER.

MAKE A CONNECTION

DON'T MISS
Robin Ince's festive variety show returns to London in December, with special guests Jim Al-Khalili, Lucie Green, Adam Rutherford, Josie Long and our very own Helen Czerski. For more information, see Cosmicshambles.com

PHOTO: PAUL WILKINSON/ROYAL INSTITUTION

Words, contrary to what the Bee Gees might have sung, aren't all we have. From our body language to our facial expressions, we communicate in myriad ways. Neuroscientist Prof Sophie Scott is a communication expert, and in this year's Royal Institution Christmas Lectures, she'll be looking at the language of life in all its forms, from the strange science of laughter to how technology is transforming the way we interact. Here, she chats to James Lloyd…

How much of our communication is linked to the actual words we speak?
Words are a critical part of communication, but there are many other ways in which we express ourselves. Take the voice itself, for example. You can't see me right now, but you could have a good guess at my age, geographical origins, mood and health, all from the way I'm talking. Our voices change throughout our lives. As women go through the menopause, for instance, their voices tend to get lower in pitch, while men's voices get higher as they age. There are social and cultural factors, too. Prior to puberty, boys and girls should theoretically speak at the same pitch because they're the same size, but we find that boys speak with lower voices – they're already picking up characteristics from the men around them.

And we communicate with our bodies as well, don't we?
Yes, we use our facial expressions, eye movements and body language. A lot of this is intuitive and outside our awareness: after a conversation, you tend to remember the gist of what's been said, but it can be harder to pull out the subtler things going on. You can train yourself to pick up on people's transient facial expressions, but a lot of communication is down to the other person's interpretation of the interaction.

Can we train ourselves to use body language more effectively?
It must be possible, because if you look at actors, dancers and singers, they learn to use their bodies in an authentic way: you believe in their performance. But with people who've had a bit of body language training, it's like we can see their effort. It's the same with bad acting. We're so good at using these cues to work out someone's state of mind that as soon as something's not quite right, we pick up on that lack of authenticity.

Laughter is something else we often fake. How do you spot a fake laugh?
If you think back to the last time you couldn't stop laughing, that's the most spontaneous kind of laughter. You just have to let it work its way through – you're lost to the laughter for a while. If the laughter stops and starts quite quickly, then it's being used more communicatively. But this more controlled type of laughter is a useful social skill. We can use it to change a mildly difficult situation into a positive, safe one.

Why did laughter come about in the first place?
We're not the only animals who laugh. We see it in rats – they make a kind of ultrasonic squeaking when tickled – and great apes, and there's probably more out there too. Wherever we've found laughter, it's associated with babies being tickled by their parents, so its initial role seems to be in social bonding. It may be an invitation to play – a way for animals to learn and explore social roles without getting hurt. It's the same for adult humans. We think we're laughing at jokes and humour, but we're laughing just as much for social reasons, to show that we like and agree with the people we're with.

We think we're laughing at jokes, but we're laughing just as much for social reasons

What impact is modern technology having on communication?
There have always been ways to communicate that aren't face-to-face. My grandparents' generation lived at a time when the post was so quick they could have a conversation using postcards! We're very good at exploiting new technologies to help us share messages. One of the first things we did with mobile phones was to send text messages, which no one saw coming. There's some data from [evolutionary psychologist] Robin Dunbar's lab which shows that face-to-face interaction – live or on-screen – leads to people feeling happier and laughing more than just listening to each other, and then the happiness drops off again for text-based interactions. But this study was done a few years ago, and I wonder if that's changed now with all the ways we use GIFs and emojis. Whatever happens, I think communication is always going to be rooted in face-to-face interaction, because that's how we learn to use speech as we grow up.

Can emojis ever be an effective way to communicate?
We have a long history of using punctuation to change the emotional tone of our writing, and that's just what we're doing with emoticons and emojis. We're not going to be comfortable sending emojis to everyone – I'm unlikely to start sending messages full of them to the dean of my university – but they can show you things you didn't know you needed. I was struck by the number of emojis for approval: the 100 per cent sign, OK fingers, clapping hands, thumbs up. It's great – I can give somebody feedback without having to write a long essay on why I thought that was a funny tweet.

What do you hope your audience will take away from your lectures?
I hope I'll be able to do justice to the sheer complexity of communication, from basic signals like "I'm a dangerous wasp" through to the possibilities of the human voice. And one of the really powerful things about the Christmas Lectures is that they can show there are all these different ways of being a scientist. Male, female, younger, older – there's not just one way of doing it or one route to getting there. Hopefully that'll help to shift some of the stereotypes.

Sophie Scott will be presenting this year's Christmas Lectures

BBC FOUR
ROYAL INSTITUTION CHRISTMAS LECTURES
BBC FOUR, 26-28 DECEMBER.

PHOTOS: PAUL WILKINSON/ROYAL INSTITUTION, BBC, GETTY

HOSTS OF CHRISTMAS PAST

Three classic Christmas Lecture series to watch online at rigb.org/christmas-lectures

DAVID ATTENBOROUGH
1973

Attenborough's six lectures on The Language Of Animals *shattered the cardinal rule of showbiz, "never work with animals or children". Among the creatures on show were a praying mantis, a ring-tailed lemur and an impossibly cute baby orangutan.*

CARL SAGAN
1977

In possibly the most iconic lectures of all, Sagan discussed our place in the Solar System and the game-changing discoveries made by the Mariner 9 and Viking missions to Mars. It was a fertile time for space exploration, with the twin Voyager spacecraft launched just a few months earlier.

SUE HARTLEY
2009

The botanical world was brought memorably to life by Hartley, with chocolate fountains, giant marrows and mouth-burning chillis all helping to demonstrate the ways in which plants cling to survival, and how we've manipulated plants to suit our own needs.

CHRISTMAS BOOKS GUIDE

02 CURL UP WITH A BOOK

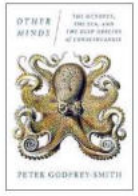
There's no time like Christmas to get lost in a book. Here are 13 of our favourite long reads of the year

THE ANIMALS AMONG US

JOHN BRADSHAW

£20, ALLEN LANE

Why do we keep pets? Bradshaw argues that it goes beyond cuteness and companionship, and all the way back to an ancient connection in our shared past. Weaving together psychology and evolutionary science, the book will give pet owners a newfound appreciation for their furry friends.

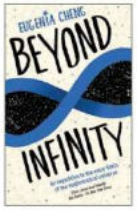


OTHER MINDS

PETER GODFREY-SMITH

£20, WILLIAM COLLINS

The octopus is essentially an alien species right here on Earth – a sentient being whose intelligence has evolved entirely independently from our own. Godfrey-Smith peers into the minds of these cephalopods, revealing what they can tell us about the nature of consciousness itself.

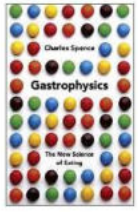


BEYOND INFINITY

EUGENIA CHENG

£12.99, PROFILE BOOKS

It takes a talented writer to bring the concept of infinity to life, but Cheng's infectious enthusiasm makes maths a delight. Discover why some infinities are bigger than others, and why there's always room at an infinite hotel, even if it's full.



GASTROPHYSICS

CHARLES SPENCE

£16.99, VIKING

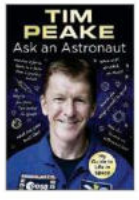
In this breezy introduction to the new science of gastrophysics, Spence explains why our mealtimes are a truly multisensory experience. It turns out that everything from the background music to the colour and shape of our plates affects the taste of our food.

TESTOSTERONE REX

CORDELIA FINE

£14.99, ICON BOOKS

The winner of this year's Royal Society books prize, Fine cuts through gender stereotypes with panache, dispelling the myth that testosterone creates a deep-rooted division between the sexes and discussing what this means for the society we live in.



ASK AN ASTRONAUT

TIM PEAKE

£20, CENTURY

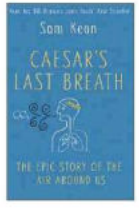
Who better to describe life in space than someone who's walked the (space)walk? Tim pens answers to the public's burning questions, revealing what space smells like, how he enjoyed a cosmic cuppa, and what it felt like to return to Earth.

INFERIOR

ANGELA SAINI

£12.99, FOURTH ESTATE

The second book on our list to tackle gender stereotypes, Saini discusses how centuries of science have painted a distorted picture of sex differences, the impact this has had on women in society, and how we're finally beginning to redress the balance.

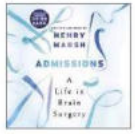


CAESAR'S LAST BREATH

SAM KEAN

£20, DOUBLEDAY

Every breath we take tells a story as old as the Earth. Kean's eye-opening guide to the science and history of our atmosphere takes in everything from radioactive pigs and spontaneous combustion to Julius Caesar's final moments and some unforgettable performance art at the Moulin Rouge.



ADMISSIONS

HENRY MARSH

£16.99, WEIDENFELD & NICOLSON

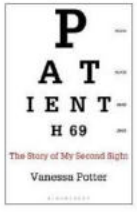
Following up 2014's much-lauded *Do No Harm* was never going to be easy, but this second part of Henry Marsh's memoir is an equally honest, human and beautifully written account of the ups and downs of his life as a brain surgeon.

TO BE A MACHINE

MARK O'CONNELL

£12.99, GRANTA

With shades of Jon Ronson and Louis Theroux, O'Connell explores the world of transhumanism, meeting the cyborgs, utopians and futurists who hope to use technology to improve the human condition. It makes for an engrossing, witty and at times disturbing read.



PATIENT H69

VANESSA POTTER

£16.99, BLOOMSBURY SIGMA

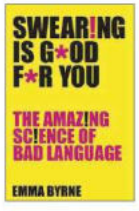
One day, Vanessa Potter started to lose her sight. Within three days, she was completely blind. *Patient H69* documents her descent into darkness – and her subsequent recovery as, armed with scientific insight, she began to make sense of her unique condition.

THE ANGRY CHEF

ANTHONY WARNER

£12.99, ONEWORLD

Paleo, GAPS, alkaline, detox... so many diets, but do any of them actually work? With scientific rigour and a generous helping of expletives, Warner takes on the food fads one by one, and asks why we're so easily taken in by pseudoscience in the first place.



SWEARING IS GOOD FOR YOU

EMMA BYRNE

£12.99, PROFILE BOOKS

The next time someone tells you off for swearing, give them a copy of this book. Byrne explains all the ways in which swearing is good for us, from pain relief to team bonding, and reveals what cursing chimpanzees can tell us about the origin of dirty words.

03 SOLVE A PUZZLE

Three of this Christmas's best puzzle books, with one puzzle from each to whet your appetite...

ONLY CONNECT: THE OFFICIAL QUIZ BOOK

JACK WALEY-COHEN

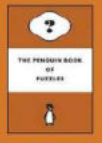
£14.99, BBC BOOKS

TV's most fiendish quiz gets its own book, so put on your lateral thinking cap and start looking for those hidden connections.

MISSING VOWELS

The titles of four nursery rhymes have had their vowels removed and their consonants respaced. How quickly can you decipher them?

NTWB CKLM YSH
LDK NGC L
PPG STHW SL
RNG SN DLM NS



THE PENGUIN BOOK OF PUZZLES

DR GARETH MOORE

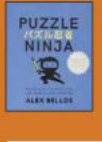
£12.99, MICHAEL JOSEPH

A feast of brainteasers from across the centuries. Try your hand at word games, maths challenges, logic conundrums and more.

ARITHMETIC SQUARE

Place each number from 1 to 9 into the cells (a different single number in each cell) so that the indicated equations are correct. Evaluate from left-to-right and top-to-bottom.

□	× □	− □	= 10
×	−	+	
□	− □	− □	= 0
−	−	+	
□	− □	+ □	= 12
=	=	=	
10	0	12	



PUZZLE NINJA

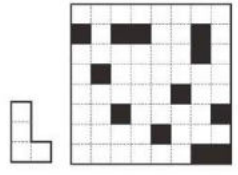
ALEX BELLOS

£14.99, GUARDIAN FABER

Try your hand at over 200 challenges from Japan. The 20+ puzzle types are rated easy to excruciating, and there's not a Sudoku in sight.

L-PANEL

Divide the grid into L-shaped tiles, like the one below, made up of four cells each. Every white cell must be in an L-shaped tile, with no cells left over. Probably best to use a pencil!

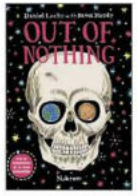


For the solutions head to: bit.ly/focusanswers

GET GRAPHICAL

CHRISTMAS BOOKS GUIDE

04 This year has seen a wealth of beautiful, science-themed graphic novels and illustrated books. Here are some of our favourites...

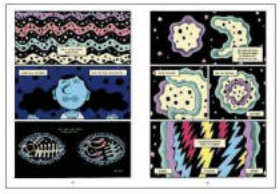


OUT OF NOTHING

DANIEL LOCKE & DAVID BLANDY

£14.99, NOBROW

Combining science fact with dreamlike imagery, Locke and Blandy's eye-popping graphic novel celebrates the ingenuity of the human mind. We travel across centuries from Gutenberg's printing press to Tim Berners-Lee's World Wide Web, via Picasso, Einstein, Rosalind Franklin and more.

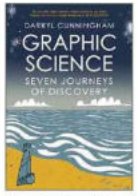


WOMEN IN SCIENCE

RACHEL IGNOTOFSKY

£12.99, WREN & ROOK

Discover (or rediscover) the work of 50 trailblazing female scientists in Ignotofsky's gorgeously illustrated book. Familiar names like Marie Curie and Ada Lovelace sit alongside lesser-known pioneers such as Maria Sibylla Merian, one of the first and more important entomologists.

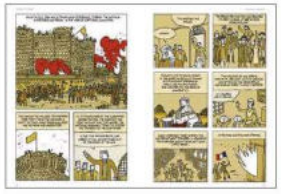


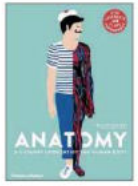
GRAPHIC SCIENCE

DARRYL CUNNINGHAM

£16.99, MYRIAD EDITIONS

With his crisp comic art, Cunningham tells the stories of seven scientists who history has rather overlooked. Mary Anning, Alfred Wegener, Fred Hoyle, Jocelyn Bell Burnell... they're names you may have heard of, but *Graphic Science* underlines the importance of their work.





ANATOMY

HÉLÈNE DRUVERT & JEAN-CLAUDE DRUVERT

£18.95, THAMES & HUDSON

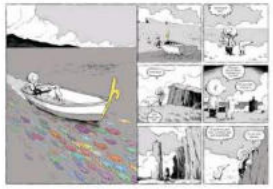
A cutaway book of the human body, *Anatomy* elicited gasps of delight in the office. Its flaps and delicate lasercuts allow kids to explore the organs, systems and senses that keep us alive, while the accompanying text provides a nice introduction to human biology.

MYSTERIES OF THE QUANTUM UNIVERSE

THIBAULT DAMOUR & MATHIEU BURNIAT

£17.99, PARTICULAR BOOKS

Billed as 'Tintin meets Brian Cox', this book performs the tricky task of making quantum physics accessible. Join Bob and his dog Rick on a journey through the world of the very small, talking atoms with Einstein and eating crêpes with Max Planck.



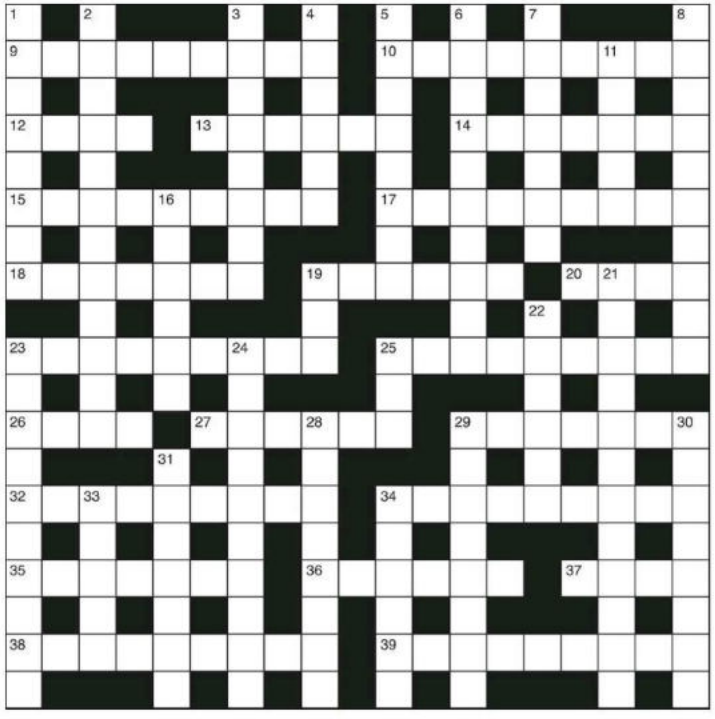
THE LOST WORDS

ROBERT MACFARLANE & JACKIE MORRIS

£20, HAMISH HAMILTON

Worried by the way in which natural words (acorn, dandelion, kingfisher, etc) are disappearing from children's vocabulary, Robert Macfarlane has teamed up with illustrator Jackie Morris to produce this exquisite 'spell book', combining acrostic poems with hand-painted artwork.

BBC FOCUS CROSSWORD
GIVE YOUR BRAIN A WORKOUT



DOWN

1 Owns CID is returning to form of Judaism (8)
2 Haphazard entry on computer memory (6,6)
3 Rearranging did spoil some cells (8)
4 Female soldier to endlessly astound old and new (6)
5 Cleaner firm with a trainee getting fuel (8)
6 Formed rind another way, like a tree (10)
7 Youngster to drain fish (7)
8 Show Arctic conditions to be egalitarian (10)
11 Picture current game differently (5)
16 Improvise some pasta (6)
19 Prattle like an ox (3)
21 King orders tutorial, how to get some energy (8-4)
22 Girls cooking European salmon (6)
23 Armies' task, organising source of uranium (10)
24 Plane used to supply walking stick (10)
25 Fellow finds a time to blubber (3)
28 Inexperienced, run away from pest (8)
29 Musical not so much like Cats – at least some (8)
30 Gifted, thanks to fast journalist (8)
31 Diamonds come down in the country (7)
33 Pick-me-up, often after gin (5)
34 An eccentric gets one tick (6)

ACROSS

9 Maids came out for conventional attitude (9)
10 Laugh at English friend taking it for a mineral (9)
12 Thus get attorney a drink (4)
13 Jacket right behind conflagration (6)
14 Lodged a revision for cape in Mozambique (7)
15 Feature of time, say (9)
17 Retire one plan to use a compass (9)
18 Endless series on military exercises for Polyphemus, say (7)
19 A shade craven (6)
20 Comedy sketch set in his kitchen (4)
23 Explosive returned by old sailor (9)
25 Claim four worked like a vent (9)
26 Plant doctor on ship (4)
27 Peg gets drunk with swine (6)
29 Idiot is not much of a comedian (7)
32 Recent ice formation shows restraint (9)
34 Let animal get confused about food (9)
35 Allow piece to start for warbler (7)
36 Nitrogen in advance? Not quite (6)
37 Feature of each individual (4)
38 Nice latch, terribly specialised (9)
39 Appoint to a scientific organisation (9)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW**
Please be aware the website address is case-sensitive.

MY LIFE SCIENTIFIC

Prof Raj Lada

Helen Pilcher quizzes the founder of the Christmas Tree Research Centre to find out his secret formula for avoiding a carpet covered in pine needles...

In Atlantic Canada, the growing of Christmas trees isn't just something to worry about in the winter – it's a year-round industry that employs 20,000 people

I hate sweeping up Christmas tree needles. Can you help?
Yes. Needle loss is a big problem. In Atlantic Canada where I work, Christmas trees are a $100m industry. We export three million trees annually, but in the past entire shipments have been lost when the trees lost their needles. It struck me that no one had a clue what was going on. So seven years ago I founded the Christmas Tree Research Centre to find out.

What causes needle loss?
All our work is in our native balsam fir. We've compared trees that lose their needles quickly with trees that keep them for longer, and found many different factors that contribute. You see changes in the levels of various genes, enzymes, lipids and nutrients. We've identified a key hormone, ethylene, that is involved, as well as over a dozen different volatile compounds that promote needle loss.

Should I water my tree?
Absolutely. It's essential.

Is there anything I can buy to help my tree keep its needles?
It's not in the shops yet, but we've created something that doubles the time your tree will keep its needles. You add it to the water.

Can you tell me what's in it? Or is it a bit like the recipe for Coca-Cola?
All our work is protected by confidentiality agreements, so I have to keep it a secret. Sorry!

Do fairy lights affect needle loss?
Yes, they can actually help. We tested different coloured LED lights and found that white and blue bulbs can increase needle retention by around 120 per cent. Trees also keep their needles longer if they experience a brief cold spell close to cutting. So we've developed technologies to help with that. We could ship our trees around the world three times without them dropping needles.

How about cloning the perfect tree?
We've created something that we call the SMART Christmas tree. We crossed together trees with the best shape and highest needle retention, then used tissue culture methods to make new seedlings. We now have some trees that are over a year old, but they're not technically clones because they contain genetic material from two parents and not from any other source.

Where can I get one?
The embryonic seedlings are currently being mass produced and offered to industry. Next year we anticipate a million seedlings will be ready for planting, but it will be a while before the trees are available to buy. A 150cm balsam fir can take 10 years to grow.

What's the best tree to buy now?
My favourite is still the balsam fir. We always have one. It's a good-looking tree and has a beautiful fragrance.

Have you ever had an artificial tree?
No. I never would.

And finally: star or fairy?
I have a star on my tree, always.

Prof Raj Lada is founding director of the Christmas Tree Research Centre at Dalhousie University, Canada.

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